PRACTICAL PROBLEMS IN BOTANY

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NEW YORK

JOHN WILEY & SONS, INC.

LONDON: CHAPMAN & HALL, LIMITED

1936

PRINTED IN U. S. A.

PRESS OF
BRAUNWORTH & CO., INC.
BUILDERS OF BOOKS
BRIDGEPORT, CONN.

PREFACE

It is the belief of the authors of this book that no subject contributes more, when properly taught, to the attainment of the cardinal principles of secondary education than does biological science. It is the main province of this text to lay a foundation of fundamental principles which will enable pupils to develop an understanding of the significance of plant life which is such an important part of their environment. Moreover, the work in botany should be made practical in the sense that it should supply a basis of fact necessary to an understanding of principles, so that the student can use them in developing within himself a degree of social, civic, ethical, and esthetic efficiency.

A practical course in botany should aid in developing an appreciation of the possibilities of improvement of the home environment through putting into practice a knowledge of the principles of plant growth. Window-plant culture, landscaping of home grounds, vegetable and flower gardening not only contribute to the attractiveness of the home, but they also provide pleasant and profitable avocations as worthy use of leisure time. Also, knowledge of foods, bacteria, and the laws of sanitation, and the life out-of-doors occasioned by engaging in vocations and avocations along the lines of plant study and plant culture, both tend toward personal efficiency by making the person a healthier individual.

Certain aims and objectives have been set up. The problems and exercises are such as to be a direct aid in the attainment of these aims and objectives. The teacher who administers the course should not only have in mind the general objectives, but he should also recognize locally adapted specific objectives which should aid in determining points of special emphasis. Local conditions which affect specific aims include: dominant interests of pupils, community interests and needs, and availability of local resources, as woods and streams, greenhouses, parks, farms,

health laboratories, landscaped homes, milk-pasteurizing plants, canneries, and facilities for sewage disposal.

The problem involves learning activities which when properly directed by the teacher and carried out by the pupil will lead to the development of significant biological ideas and to the acquisition of the elements of scientific thinking.

The course is organized as a series of problems and subproblems. It is intended that each problem shall lead pupils inductively to an understanding of important generalizations. The introduction of the book is an over-view of the entire course, and the introduction of each unit is an over-view of that unit. Provision is made for meeting individual differences by including suggested activities and additional exercises and problems which may be done by pupils who are able to finish the required work ahead of the majority of the class.

The arrangement of the units is logical as it stands, but it is not intended as the best order under all conditions. Teachers who prefer a seasonal arrangement will find it possible to change the order of presentation of units to suit their requirements. A course beginning at mid-year will require an arrangement of units different from that which is best for a course beginning in the fall.

Teachers are referred to *The Teaching of Biology*, by William E. Cole, published by D. Appleton–Century Company, for helpful suggestions regarding points of view in biology, laboratories, equipment, bibliographies, and materials.

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September 9, 1935.

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INTRODUCTION

Wherever man has gone on the earth he has found some kind of plant life. Expeditions to arctic and antarctic regions, to the tops of the highest mountains, into the sandy stretches of the driest deserts, to all parts of the world, have always revealed some form of plant life. In the ocean, in both fresh- and salt-water lakes, in ponds and streams, in drinking water, in the waters of hot springs, there is an abundance of plant life. Certain bacteria, fungi, and algae occur in countless numbers in the soil, without which organisms soil fertility would not be maintained; bacteria and fungi are ever-present in the air, stealing rides on floating dust particles; bacteria are also always present in the digestive tracts of all kinds of animals; in fact, both plants and animals serve as hosts to many different kinds of bacteria and fungi, some harmless, or even beneficial, others disease-causing. Name five diseases of man caused by bacteria.

In Schimper's *Plant Geography*, a monumental work of 839 pages and 502 illustrations, published by the Clarendon Press, Oxford, England, we find the following:

"As has been already shown, there is nowhere on earth a place too cold for plant life, and only a few spots of very limited area that are too hot. As regards light, there is no limitation; it is nowhere too dark, nowhere too bright to exclude plant life of some kind. In the depths of the ocean, where light is absolutely absent, the decaying corpses of animals are decomposed by bacteria. . . . In the well-known Guacharo Cave near Caribe in Venezuela we found the ground covered with patches of dense etiolated vegetation up to half a meter in height, which had sprung up from the dung of the Guacharo birds, the only inhabitants of the Cave."

Further, Schimper says: "The perpetual snow and ice of the polar zone and of mountains, here and there, exhibit conspicuous coloring caused by microscopic algae. . . . The occurrence of algae associated with red snow has been demonstrated on the most distant points in the Arctic and Antarctic zones and on most mountains with perpetual snow, so that the phenomenon may be assumed to be of general distribution."

Schimper quotes from Volkens' description of the vegetation on the highest peaks of Kilimanjara, a mountain of Africa which attains an elevation of 6010 meters. Volkens says, "Finally, at 4500 meters we have reached the last outposts, all isolated plants, forming little cushions under the shelter of stones. . . . Beyond this, wherever the ground is dry, only lichens and mosses prevail."

Thus we see that **plants invade all sorts of environments,** that is, they live under all kinds of conditions. To do so successfully, they must be fitted to the conditions of their surroundings. Most certainly land plants can not live in the water; and ordinary, thin-leaved water plants would soon succumb if transplanted to a dry hillside. Why? Plants accustomed to the shade of the forest floor do not survive if the forest is cut or burned over; and plants of the open can not thrive in the shade. The ability of plants to live in all sorts of environments is possible only because of their great variation in form and structure. For example, plants of the desert must possess those characteristics which enable them to survive where water is scarce. Some of these so-called drought-resistant characteristics are: water-storage tissue, greatly reduced leaf surface, and thick coverings on the leaves which cut down water loss. Many plants of high mountains are low and mat-forming, thus getting the warmth close to the soil and avoiding the greater loss of water which would occur if they grew several feet tall.

One has only to examine plants growing under varied conditions to learn how well they are fitted to their environment. How are lichens able to live upon bare rock surfaces? How can certain orchids manage to survive on the branches of trees without any connection with the soil? How can cacti and many other plants live in the desert where the rainfall is but a few inches a year? What peculiarities do those plants have which can thrive

in alkali flats? What structures enable the cypress to grow in swamps where water always covers the roots? Why is it possible to grow Durum wheat and certain sorghums on the dry plains of western United States without irrigation, whereas many other crops will not thrive there without irrigation? What characteristics would you expect those plants to have which can grow successfully in acid bogs? These are suggestive of the problems confronting the student who would know the relation of plants to their environment.

Plants are living things. True it is they do not move about from place to place, as do most animals. But they manifest all the essential characters that we associate with livingness. Plants absorb materials from the outside world; they make food; they digest food; they respire; they make plant substances out of foods; they grow; they are sensitive to light, gravity, moisture, heat, and other environmental factors; they reproduce. Plants are indeed living things—organisms.

The fundamental organization and composition of plants and animals are quite similar. The unit of structure in both plants and animals is the **cell,** a microscopic sac containing the living stuff—**protoplasm.** The cells are grouped to form **tissues,** such as absorbing tissue, conducting tissue, protective tissue, storage tissue, reproductive tissue, etc.; and the tissues are grouped to form **organs**, such as roots, leaves, stems, flowers, fruit, and seed.

There are no chemical elements found in animals that do not occur in plants. This is a rather remarkable fact. In both, the principal elements which enter into the composition of the body are oxygen, potassium, magnesium, hydrogen, nitrogen, sulphur, phosphorus, and carbon. These are common elements which occur in the air and soil. **The foods of plants and animals are the same.** At first thought, we may question this statement. But the foods of both plants and animals are carbohydrates (sugars, starch, cellulose, etc.), fats, and proteins. What are the chemical characteristics of these three groups of foods? **The processes of absorption, digestion, respiration, assimilation, growth, and reproduction are essentially alike in plants and animals.** This statement may also arouse doubt in the mind of the reader, but the discussion of these processes which will come in succeeding units

will assist in removing this doubt. Of course, there are marked differences between plants and animals. For example, the great majority of plants are not able to move from place to place, whereas locomotion is characteristic of most animals; in the majority of plants each of the cells is surrounded by a relatively rigid wall, whereas the cells of animals are usually without such surrounding walls; from the very simple substances such as water, carbon dioxide, and mineral salts, obtained from the soil and air, most plants can build the foods necessary to nourish their bodies, whereas animals are unable to make their own foods; and the growth in length of most plants takes place at or near the ends of the organs, such growth generally continuing as long as the plant is alive, whereas in animals, growth is not usually restricted to the extremities, and ceases long before death.

It is of interest to note that the very simplest plants and the very simplest animals, both groups of which are aquatic, have much more in common than do higher plants and higher animals. In fact, there is substantial evidence that **the plant and animal kingdoms had a common ancestor**; that, in the process of development of the races of plants and animals, the distinction between these two great groups of living things has become greater and greater. But they have retained, by virtue of their common ancestry, many essential features. In other words, **life on this earth is much the same whether it expresses itself in plants or animals.**

The present assemblage of plants in the world varies greatly in complexity. The ordinary trees, shrubs, and herbs are relatively complex plants, by which we mean that they possess many different organs and tissues for carrying on their life activities. For example, they have roots, stems, leaves, flowers, fruit, and seed. There are many plants, such as the pond scums, seaweeds, bacteria, molds, mushrooms, etc., which do not have roots, stems, leaves, flowers, or seed. Such plants are simple in their bodily organization. Moreover, their methods of reproduction are not as complex and advanced as in seed plants. Then, there are such plants as mosses, liverworts, and ferns, which have roots or root-like structures, stems, and leaves, but no flowers or seeds. It is regarded by students of plant life, who have carefully examined and

compared the structure of a great many different kinds of plants and their methods of reproduction and coupled this with a study of fossil plants (Fig. 173), that during the past hundreds of thousands of years as life developed on the earth there has been great change in the nature of plants. There is reliable evidence that **the first plants that appeared on the earth were water plants,** similar in many particulars to our present-day pond scums; that from these primitive ancestors there developed more complex plants, such as liverworts and mosses; that, as the thousands of years passed by, there appeared ferns and their allies; and that from certain fern-like plants were developed our present-day seed plants. Seed plants are regarded as the most advanced and most complex of plants, just as man is considered the most advanced and complex of animals.

The plant world as we see it today is not as it always was in the earth's history. For example, geological records show unmistakably that the vegetative covering of a large part of the earth during the Carboniferous or Coal Age was composed chiefly of giant ferns and closely related forms. Seed plants as we know them today appeared much later. But the important point to keep in mind is that **plants of the past are the ancestors of those populating the earth now.** There has been a gradual development of the plant kingdom extending over a period of many hundreds of thousands of years, and **this process of development or unfolding is still going on today.**

Green plants are the great converters of solar energy. Without them, animal life on the earth would be impossible. Green plants are the only organisms on the earth which have the power to convert light energy into food energy. Green plants alone can take materials from the soil and air, and with the aid of light, change these materials into food—the food of both plants and animals. Animals and non-green plants must have their foods prepared for them; they are dependent organisms. Green plants, on the other hand, are independent in that they make their own foods. Just like any other manufacturing process, that of food-making by green plants requires energy; to build up foods from simple materials derived from the soil and air, energy is needed. This energy comes from light. **And it is through the medium of**

green plants that light energy is transformed to food energy. When wood is burned, energy is liberated in the form of heat. In burning, the energy of the chemical compounds composing wood is transformed to heat energy. But in the building of these chemical compounds which compose food, light energy is necessary. Hence the energy set free in burning wood is in reality solar energy. When coal is burned there is liberated light energy which came to the earth hundreds of thousands of years ago, which energy was utilized by the plants of that period, transformed into plant tissue, which later formed coal.

When plants respire, there is a destruction of plant substance, accompanied by the liberation of energy. To build plant substance there is required, in the last analysis, solar energy. Hence, **the energy freed in respiration is transformed solar energy.** Is energy liberated when we, as humans, respire? Explain.

Whatever way one may consider it, the fact remains that **all life on this earth depends upon light energy**—and it is only green plants that are capable of transforming this light energy into a form which can be used by plants and animals alike as food.

Plants are of great economic importance. They furnish food, clothing, and shelter. The great civilizations of the world have developed where natural conditions favored the cultivation of certain food plants, chiefly cereals. Consider the importance of such products of plant origin as wood, coal, cork, fiber, resins and turpentine, gums, plant dyes, fixed and volatile oils, and rubber. Many plants yield valued drugs, such as morphine, quinine, digitalin, and atropine. Many species are of ornamental value, being employed to beautify our homes, gardens, and parks. A large number of plants are of economic importance because they are harmful, or interfere with man's operations. Consider here the plants which cause rusts, smuts, molds, mildews, and other plant diseases; also poisonous plants, hay-fever plants, and weeds.

Botany, the science which deals with plants, is today an extremely important field of study. A knowledge of plants—their structure, their behavior, their relation to the environment, their classification and naming, their improvement by breeding and selection, their relation to diseases of useful plants and of animals—is as essential to a proper understanding of agriculture in

all its many branches, and to certain phases of medicine, as is mathematics to advancement in the field of engineering. For the individual seeking a life work, there are innumerable opportunities in the field of botany. In the educational institutions of the country—universities, colleges, and high schools—there are many technically trained botanists, specialists in some branch of plant science. These individuals are either teachers or research workers, or both. There are systematic botanists, plant morphologists, plant cytologists, plant geneticists, etc. In the United States Department of Agriculture, and in the agricultural experiment stations, of which there is one or more in each of the states, there are altogether several thousand workers, trained in some special field of botany. In addition to these, individuals equipped with a knowledge of some phase of plant science are found in the employ of botanical gardens, of museums, of national parks, of large companies which grow drug plants, sugar plants, nursery stock, seeds, rubber, tobacco, fruits, vegetables, fibers, and other industrial plants.

In addition to these botany specialists, a certain knowledge of plants is usually required of those whose major interest may be in such fields as zoology, entomology, geology, pharmacology, animal husbandry, veterinary medicine, bacteriology, soil technology, irrigation practice, etc. (NOTE: If the student does not know what the above sciences treat of, he should attempt to find out. Consult dictionary or encyclopedia, or special books.)

The student may gain some knowledge of the number of botanists in the United States, and the character of the positions they hold, from *American Men of Science, a Biographical Directory*, edited by J. McKeen and Jaques Cattell, and published by the Science Press, New York. The fifth edition has 1278 pages.

SELECTED REFERENCES

Ernest H. Wilson, Plant Hunter, by EDWARD I. FARRINGTON, is a well-illustrated book of 187 pages, published by the Stratford Company, Boston. 1931. This book describes the colorful adventures of Ernest Wilson in his search for plants in various parts of the world.

The Geography of Plants, by M. E. Hardy, published by the Clarendon Press, Oxford, England. 1920. A brief description of the plant life characteristic of different parts of the world. 327 pages, 114 illustrations.

An Outline of Plant Geography, by DOUGLAS HOUGHTON CAMPBELL, published by the Macmillan Company, New York. 1926. "For more than thirty years the writer has made excursions into many parts of the world, and the specimens, notes, sketches and photographs accumulated during these journeys have served as the basis of the present volume." 392 pages, 153 illustrations.

America's Greatest Garden, the Arnold Arboretum, by E. H. WILSON, published by the Stratford Company, Boston. 1925. This is "a note of invitation to a banquet of flowers and fruit provided by an assemblage of the World's best hardy trees and shrubs." 123 pages and 50 full-page illustrations of great beauty and interest.

Tree Ancestors, a Glimpse into the Past, by E. W. BERRY, published by Williams and Wilkins Company, Baltimore. 1923. The sketches of the book are "an attempt to interest the general public in the marvellous history of some of our trees." It discusses geological principles, methods of preservation of fossil plants, geological time and methods of reckoning, the later geological history of North America, the present forests of North America, and the history of such trees as the sequoias, bald cypress, walnuts, beech, magnolia, maple, ash, and many others. 270 pages and 48 illustrations.

Plant Hunting on the Edge of the World, by F. KINGDON WARD, published by Victor Gollancz, Ltd., Covent Garden, London. 1930. This is a travel book with a strong botanical flavor. The author describes his journeys to "collect seeds of beautiful hardy flowering plants for English gardens, to collect dried specimens of interesting plants for study," and "to explore unknown mountain ranges and find out something about their past history, the distribution of their plants, and any other secrets they are willing to reveal." 383 pages and 15 illustrations.

Exploring for Plants, by DAVID FAIRCHILD, published by the Macmillan Company, New York. 1930. A most interesting book by one who for many years was in charge of the Office of Foreign Plant Introduction, of the U. S. Department of Agriculture. 591 pages and 179 illustrations.

The Natural History of Plants, by ANTON KERNER and F. W. OLIVER. Published by Blackie and Son, London. 1895–96. In two volumes, Vol. I, 777 pages; Vol. II, 983 pages, with about 2000 original woodcut illustrations. A classical work replete with interesting facts about plants.

UNIT I

THE ORGANIZATION AND COMPOSITION OF PLANTS

The *human body* is made up of a number of **organs**, each with a work to do. There are organs of sight, of hearing, of digestion, of circulation, etc. The **plant body**, too, is composed of a number of organs, each having some definite work to do. For example, among **seed plants**—those plants with which we are most familiar—the roots are the absorbing and anchoring organs, the stems are the supporting and conducting organs, the leaves are the chief water-losing and food-making organs, and the flowers are the reproductive organs. But there are many plants much different from seed plants and in many respects simpler in their organization. For example, ferns have bodies with roots, stems, and a peculiar form of leaf which we call a "frond," (Fig. 177), but ferns do not have flowers and seeds. Mosses are prostrate plants, much simpler in their make-up than either seed plants or ferns; they have a very poorly developed conducting system, weak stems, extremely small leaves, no roots in the ordinary sense, and reproductive structures which have no resemblance to flowers. Still lower in the scale of plant life is that great group of plants which includes pond scums and seaweeds, bacteria and yeasts, rusts and smuts, molds and mildews, mushrooms and toadstools—plants which have no roots, stems, or leaves, and very simple reproductive organs. There are even plants, bacteria and certain algae, the entire body of which consists of a single cell. **A plant body of one cell is the simplest kind possible** (Fig. 1, A, B, C, 3).

Not only is there great variation in the structure of plants which compose the population of the world, but also there are very considerable differences in their chemical composition. For example, the sugar beet and sugar cane are richer in sugar than most other plants; oranges and lemons contain a relatively large amount of citric acid; in the seed of the castor-bean plant there is an oil known as castor oil; a latex, the basis of commercial rubber,

exists in rubber plants; the bark of *Cinchona* yields a chemical known as quinine; the coffee berry produces an alkaloid—caffein; tannins are chemical compounds derived from the bark of certain trees; and so on, there being literally thousands of chemicals manufactured in different plants. Name other chemical compounds derived from plants.

Thus we see that, among the vast assemblage of plants which clothe the earth, there is great variation in their structure, that is, their organization, and in their chemical composition.

Problem 1. What are the different forms of the plant body?

When we consider the microscopic animal life of water and land, and the vast assemblage of insects, worms, crustacea, reptiles, birds, and mammals, it would appear that almost every conceivable form of animal body is represented. Likewise in the plant kingdom is there tremendous variation in the forms of the plant body. The mention of a few plants will call to mind some of the different forms of body: seaweeds, yeast, bread mold, wheat smut, toadstools, liverworts, mosses, ferns, cycads, and the great variety of herbs, shrubs, and trees.

The simplest plant body is a single cell. Among such simple one-celled plants are the bacteria. A plant body in which cells are joined end to end to form a thread represents the next stage of advance in complexity over the one-celled forms. There are many such thread-like plants among the pond scums, seaweeds, and certain fungi. Then there is a grouping of cells to make up such simple plant bodies as toadstools and mushrooms; these are many-celled plants, but devoid of roots, stems, leaves, and flowers. Still more complex plant bodies are those of flowering plants which have many different tissues and organs with which to carry on the work of the body.

Thallus plants. There is a large group of plants known as the Thallophyta (thallus plants), to which belong the algae and the fungi. They are primitive members of the plant kingdom. The plant body is either a single cell or a simple grouping of cells to form a body that has no leaves, stems, or roots. Moreover, they do not have flowers, fruits, or seeds.

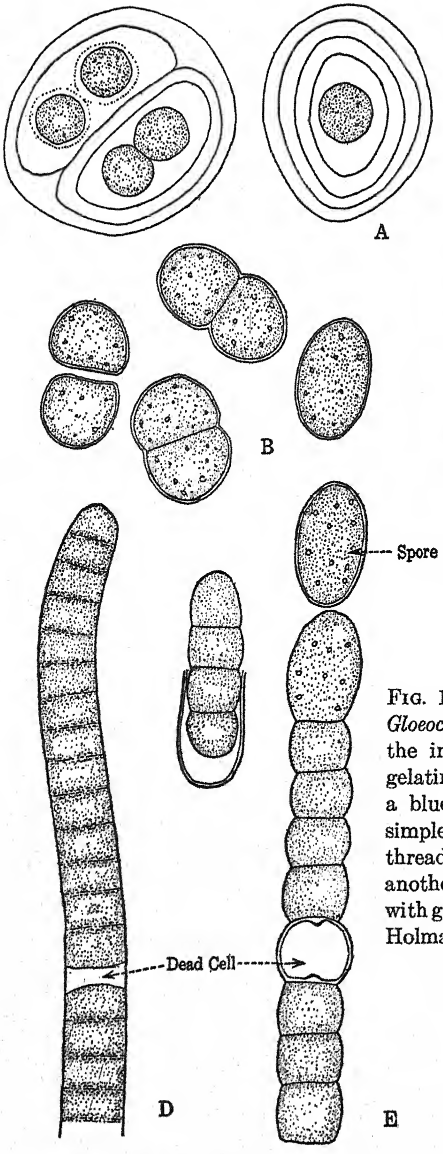

FIG. 1.—Different kinds of algae. A, *Gloeocapsa*, a blue-green alga in which the individuals are surrounded by a gelatinous coating; B, *Synechococcus*, a blue-green alga; C, *Protococcus*, a simple green alga; D, *Oscillatoria*, a thread-like blue-green alga; E, *Nostoc*, another thread-like blue-green alga; with germinating spore at left. (From Holman and Robbins, in a Textbook of General Botany.)

Algae. Algae are plants of simple structure which grow in the water or in very moist situations. We are familiar with those that

form a greenish slime on the sides and bottom of watering troughs and drinking fountains; and those that appear as a green coating on the north sides of trees in moist forests; and those that form a green, frothy, repulsive-looking scum on the water of ditches, ponds, reservoirs, and stagnant pools. Algae are found in both fresh and salt water. Many of the larger kinds in the ocean are known as "seaweeds."

Four different groups of algae. As to color, there are four groups of algae: **blue-green, green, brown,** and **red.**

The blue-green algae and green algae are chiefly of fresh waters, whereas the brown algae and the red algae are principally of salt waters. The brown algae, or brown seaweeds, are common along the shores of all oceans. They are attached by specially modified structures, holdfasts, to pilings, rocks, etc. The best-known brown algae are the giant kelps, some of which may reach a length of 800 to 900 feet; the rockweeds, which are found on the rocks between high-tide and low-tide marks; and *Sargassum,* which becomes detached from its growing places along shores, and is often carried far into the ocean. The "Sargasso Sea" in the North Atlantic Ocean is a floating mass of the brown alga, *Sargassum,* carried there by ocean currents from distant shores. It is recorded that Columbus saw the Sargasso Sea on his memorable voyage to the New World. William Beebe and Ruth Rose in *The Arcturus Adventure,* a Putnam publication, describe in a most interesting manner the "Sargasso weeds and waves."

The red algae, or red seaweeds, are quite beautiful, delicate plants and are usually much smaller than the brown algae. The plants are often very highly branched, the divisions being fine and thread-like. The red algae are found in deeper waters than the brown algae.

The simplest algae, such as *Gloeocapsa,* and *Protococcus,* are one-celled plants. The whole plant consists of but one spherical cell. What simpler plant could there be? But these microscopic one-celled plants carry on all the life processes, such as absorption of water and mineral nutrients which are taken in at all points on the plant body, respiration, food manufacture, digestion, assimilation, and reproduction.

Many of the algae are filamentous or thread-like forms. That

is, their bodies consist of a single chain of cells. Common examples of filamentous algae are: *Nostoc* and *Oscillatoria* of the blue-green algae, and *Spirogyra* and *Ulothrix* of the green algae.

Nostoc plants are often aggregated to form bluish-green balls, which may be found on damp earth or in water. The threads or filaments (the plants) are embedded in, and held together by, a gelatinous material secreted by the different cells that make up the colony. Chlorophyll is present, and with it is a blue-green pigment which gives the blue-green color to the whole cell.

Spirogyra or common pond scum is one of the most widely distributed of the green algae. Each cell as shown in Fig. 2 is a short cylinder, with well-defined walls of cellulose. Each cell has one or more conspicuous spiral chlorophyll bands. The spiral band

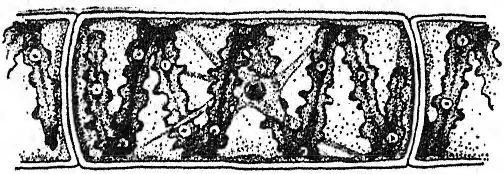

FIG. 2.—Drawing showing the structure of a cell of Spirogyra and its relation to other cells of a filament. The cell wall is lined by a thin layer of cytoplasm which holds a spiral chloroplast. This bag of cytoplasm is filled with cell sap within which is suspended a small mass of cytoplasm containing the nucleus of the cell.

is a specialized mass of living material. In addition, there will be found near the center of the cell a nucleus, and from it strands of protoplasm radiating to and connecting with the protoplasm that lines the wall.

A number of algae, such as *Cladophora*, are branching, filamentous forms. Some, like *Ulva*, consist of a single plate of cells. The brown and red algae, the " seaweeds," however, possess the most complex structure of all the algae. Their bodies may be large. In one of the rockweeds (*Ascophyllum*), for example, the plant possesses special holdfasts; it is highly branched, and the branches are of two different kinds; there are two quite distinct systems of tissues; and its reproductive organs are more complex than those in blue-green and green algae.

Thus we see that algae, as a group, vary considerably in structure. The blue-green algae include the simplest forms, many of them being simple one-celled plants. Some of the blue-green algae are filamentous. The green algae include one-celled, filamentous, and plate forms. The brown and red algae ("seaweeds") are often very large plants.

Exercise 1. Different kinds of algae. Make a microscopic study of the different forms of algae which may be collected from ponds, streams, fountains, and moist surfaces of trees and rocks. Observe principally the variations in the form of the plant body. Also, if possible, examine various kinds of brown and red seaweeds.

Fungi. The fungi are forms of plant life which have no chlorophyll and hence must secure their food ready-made from living organisms or from substances which were once a part of the bodies of living organisms. **The foods of fungi, as of all plants and animals, are chiefly carbohydrates, fats, and proteins.** As we have learned, green plants have the power of manufacturing these foods from carbon dioxide, water, and various mineral salts, that is, from inorganic materials. But the fungi, lacking chlorophyll, do not have this ability. They are dependent either directly or indirectly upon green plants.

Those fungi which gain their foods from living plants or animals are called **parasites**; those which take their foods from the dead remains or products of living plants or animals are called **saprophytes.** For example, the rusts and smuts which gain nourishment from live tissues are parasites; and the molds of bread and fruits, and the various fungi which grow on decayed logs are saprophytes. The term **host** refers to the plant or animal from which the parasite derives nourishment.

Different kinds of fungi. There are many thousand different kinds of fungi, and they affect man's welfare in many ways. It is difficult to overemphasize their importance. A number of bacteria and other fungi bring about decomposition of organic material, and are necessary to maintain soil fertility; thousands of them cause diseases of plants and animals, including man; they are essential in the making of cheese and of bread, in the retting of flax, and in many other commercial processes.

We shall discuss briefly here a few of the most important

groups of fungi, namely, bacteria, molds, mildews, yeast, smuts, rusts, mushrooms, and toadstools.

The bacteria (Fig. 3). Bacteria teem in countless millions in the air, in the soil, and in the water; they are present upon the surface of the human body, and that of other animals, and in the intestinal tract; they abound in sewage, and in all decaying material; they occur in the surface of all objects about us. **Bacteria are the smallest known organisms.** The average size is about $\frac{1}{25,000}$ inch in diameter.

There are three principal types as to shape (Fig. 3): the **spherical** (coccus), the **rod** (bacillus), and the **spiral** (spirillum).

Exercise 2. Bacteriological laboratory. If possible the student, either alone, or with the class, should visit a bacteriological laboratory. In all cities of any size there is such a laboratory connected with the city health department. Observe here the equipment, methods, bacterial cultures, etc. Take the opportunity of observing bacteria under an oil-immersion lens.

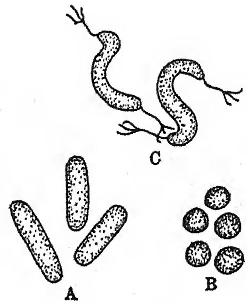

FIG. 3.—Three forms of bacteria. A, bacillus forms; B, coccus forms; C, spirillum forms.

The molds. These usually form a cobwebby growth, and they occur on a great variety of organic materials, such as stale bread, fruit and vegetables, jellies, old leather, cheese, and moist paper. Fruit and vegetables in the market, in storage, or during shipment may be greatly damaged by these saprophytic fungi, especially if the air is warm and moist. To prevent their molding, such products are shipped and stored at low temperatures, in refrigerator cars.

There are many different kinds of molds varying as to the color of the spores they produce: black, blue, brown, green, and yellow.

The mildews. There are two different groups of mildews, the **downy mildews,** and the **powdery mildews.** Both groups are parasitic. The mildews of the first group form a downy white growth upon the surface of leaves, and sometimes on that of stems and fruits. The parasite is not confined to the surface, how-

ever, but its threads enter the tissues and absorb food from them. The spores are borne in abundance on the surface of the host, and under suitable conditions will germinate immediately. Well-known destructive downy mildews are those causing the late blight of potato, and the mildew of grape, onion, lettuce, lima beans, cucumber, pumpkin, and watermelon.

The rusts. The rust fungi constitute a very large group of plants, all of which are parasites, and many of which are of great

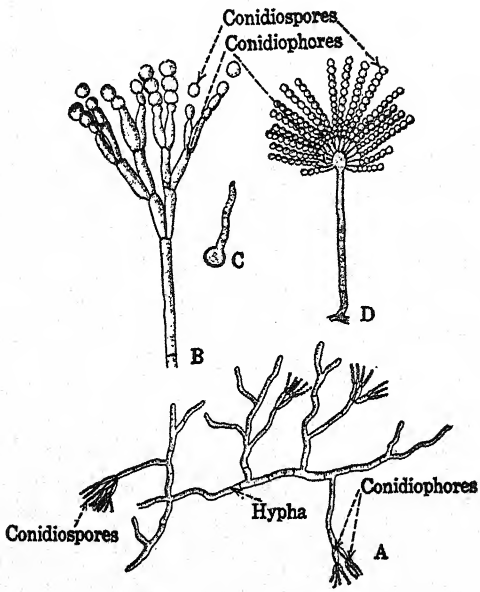

FIG. 4.—Blue and green molds. A and B, common blue mold; C, germinating spore of blue mold; D, green mold. An *hypha* is a fungous thread; *conidiophore* is a spore-bearing branch; *conidiospore* is a special type of spore. (From Holman and Robbins, in A Textbook of General Botany.)

economic importance on account of their destruction of crop plants. Among the most important rusts are those of the cereals, asparagus, apple, raspberry, and pine. The black stem rust of wheat, oats, barley, rye, and other grasses has caused damage to the cereal crops amounting to millions of dollars, and at times has become epidemic. In the United States in 1916, the black stem

rust (Fig. 43) caused a loss of wheat amounting to 200,000,000 bushels. The white pine blister rust has threatened the destruction of the white pine forests, the timber of which is valued at $411,000,000.

The smuts. All the smut fungi (Fig. 5) are parasites, occurring chiefly on members of the grass family. The annual losses of cereal crops due to the smuts frequently amount to 150,000,000 bushels. The smuts may be recognized by the black masses of

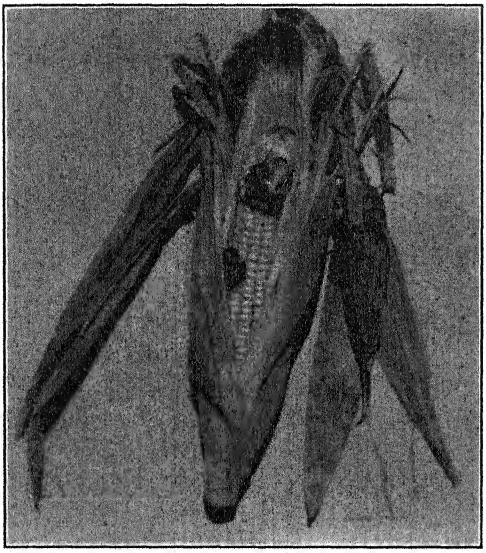

FIG. 5.—Ear of corn showing a mild attack of corn smut. Corn smut is a parasite, deriving its food from the tissues of the living corn plant.

spores. In cereal smuts these usually develop in the head and mature at about the same time the head matures.

Mushrooms and toadstoools. These are fleshy fungi which are found growing in fields, pastures, and woodlands, and also upon decaying logs and tree trunks. There is a great variety of "mushrooms" and "toadstools" (Fig. 6). Probably the best known are those which bear gills and are known as the **gill fungi** or "agarics." Others are the pore fungi, the tooth fungi, the carrion fungi, and puffballs.

Let us describe very briefly the common "meadow mushroom," the familiar edible one. The "mushroom" as we see it consists of a stalk and an umbrella-shaped cap. On the under side of the cap are thin gills. The spores are borne in enormous numbers on the surfaces of these gills. Each spore is a microscopic spherical body, light in weight, and capable of being carried long distances by air currents. The cap with its stalk, constituting the mushroom, forms in reality only a small part of the plant body. The mushroom is a fruiting body and arises from a great mass of fungous

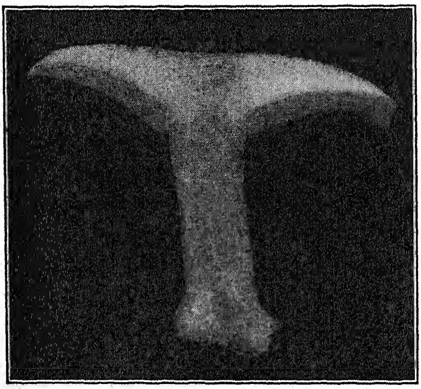

FIG. 6.—Longitudinal section of a mushroom (*Tricholoma*). The umbrella-shaped cap, or pileus, from which the spore-bearing gills hang, is supported by the stalk, or stipe.

FIG. 7.—Puffballs, showing some of the underground hypha threads.

threads which are distributed in the soil, and which gain their food from decayed organic matter.

The so-called mushroom "spawn" sold by seedsmen usually consists of dried manure containing the fungous threads, all being pressed together in brick form. When a mushroom bed is made, the spawn is broken up, mixed with earth, and used to start the beds. The mushroom originates from the fungous threads in the ground.

In the tooth fungi there are teeth or spines on the under side of the cap, and these bear the spores. In the pore fungi the spores

are borne in open tubes or pits on the under side of the cap. A number of pore fungi cause the rotting of wood. The puffballs (Fig. 7) rupture when mature, setting free black clouds of spores.

A number of the fleshy fungi are poisonous. Although there is no botanical difference between " mushrooms " and " toadstools," the former name is commonly applied to those believed to be edible, and the latter to those thought to be poisonous.

Exercise 3. The plant body of different fungi. Observe the plant bodies of a variety of fungi such as molds of bread and fruit, yeast, mildews, smuts, rusts, toadstools, and mushrooms. In what respects are they alike? In what respects do they differ?

Mosses and Liverworts. The name " moss " is applied popularly to a number of different kinds of plants. Some of the seaweeds are called " sea mosses," but the true mosses never occur in saline waters. The "Spanish moss" (*Tillandsia*) which hangs from the trees in our southern swamps is not a true moss but a flowering plant. "Reindeer moss" is a lichen, as is also the "moss" that hangs from the limbs of conifers in the northern states and in the high mountains of the West.

The **true mosses** are low plants seldom more than a few inches in height, with an erect stem, upon which very small leaves are densely crowded. The leaves are usually but one cell in thickness, except along the midrib and sometimes around the margin. There are no true roots in mosses. They possess structures known as **rhizoids,** which, although they have not the structure of roots, serve the same purposes of absorption and anchorage. Identify different moss structures shown in Fig. 104.

A distinctive feature of mosses is the " fruiting " or spore-producing body. This is a **spore-case** or **capsule** (Fig. 104) at the tip of a stalk. Numerous spores are borne within this capsule.

Mosses are found chiefly in moist woods and in swamps, but some species occur on the bark of trees and in dry rock crevices. In regions with a prolonged moist season, they may be seen growing on fences, and on the shingle roof of old buildings. They are conspicuous on account of the " carpet " or mass of vegetation they form.

The mosses are divided into three distinct groups: (1) **the peat mosses,** (2) **the black mosses,** and (3) **the true mosses.** They

differ somewhat in their appearance, structure, habits, and life history.

The **liverworts** (Fig. 107) are low-growing plants, chiefly found in moist places. The plant body is thin, green, and flat against the ground, being attached to the soil by slender root-like structures, known as rhizoids. *Marchantia* is a well-known liverwort, the body of which is more or less lobed. There are certain leafy liverworts, the body of which is composed of a slender prostrate axis or "stem" bearing three crowded rows of small leaf-like structures. The body is attached to the soil by rhizoids.

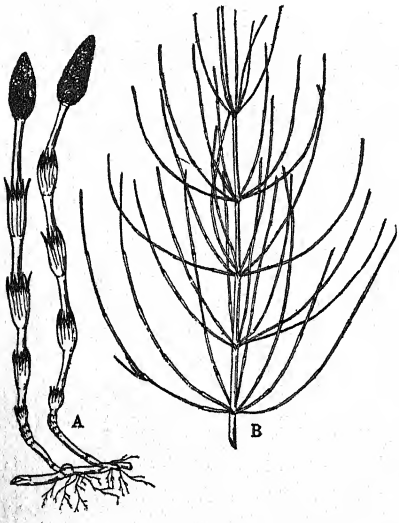

FIG. 8.—Horsetail or scouring rush. A, early spring stems arising from rootstock; note the scale-like leaves at the joints and the spore-bearing cones at the tip; B, branching form which appears later in the season than the preceding. (From Glover and Robbins, in Colo. Agr. Exp. Station Bulletin.)

Exercise 4. The plant bodies of mosses and liverworts. Observe in the field or greenhouse the plant bodies of different mosses and liverworts. Contrast them with those of the thallus plants, enumerating differences.

The ferns and their allies. The ferns and their close relatives, the club mosses and scouring rushes (horsetails) (Fig. 8), constitute a large group of plants. Like the algae, fungi, and mosses, they reproduce by means of spores, but unlike these groups, they possess woody stems and roots, and a conducting tissue, similar to that in flowering plants. The ferns and their allies do not produce flowers.

In the common cultivated ferns, the stem system is wholly under ground. It persists from year to year, growing in length at the tip, branching somewhat, and sending into the air each season a number of leaves, the so-called **fronds**. After a time there appear

on the under side of the frond brownish groups of spores which are often mistaken for some disease or insect. They are, however, the reproductive bodies. The fern-lover should read the article "Ferns as a Hobby" by William R. Maxon, in the *National Geographic Magazine*, Vol. 47, pages 541–586, 1925.

FIG. 9.—The stag-horn fern.

The **horsetails or scouring rushes** have harsh, jointed stems which arise from a rootstock. The leaves are mere scales. The spores are borne in a cone at the tip of certain branches. On account of their harsh texture, the plants have been used for cleaning and polishing utensils. They are reputed to be poisonous to livestock, chiefly horses. Sometimes they behave as weeds.

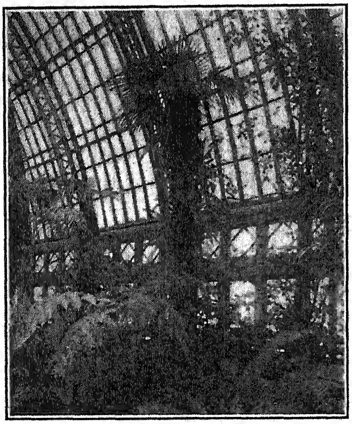

FIG. 10.—Ferns and club mosses in the Garfield Park Conservatory, Chicago.

The **club mosses** are usually creeping or trailing plants, sometimes known as "ground pine" or "running cypress." The spores are borne in leafy cones at the tips of branches. The spores are sold in drug stores under the name "lycopodium powder," and are used as a drying powder and to some extent in the manufacture of fireworks.

Exercise 5. Plant bodies of ferns and their allies. Observe in the field or greenhouse the plant bodies of different kinds of ferns, club mosses, and horsetails. Enumerate the differences between the plant bodies of ferns and their allies, and those of mosses and liverworts.

Seed plants. The seed plants possess the most complex body of all plants. There are many different organs and tissues. There

are roots, stems, leaves, flowers, fruit, and seed, except in one large group, the Gymnosperms, which have no flowers in the ordinary

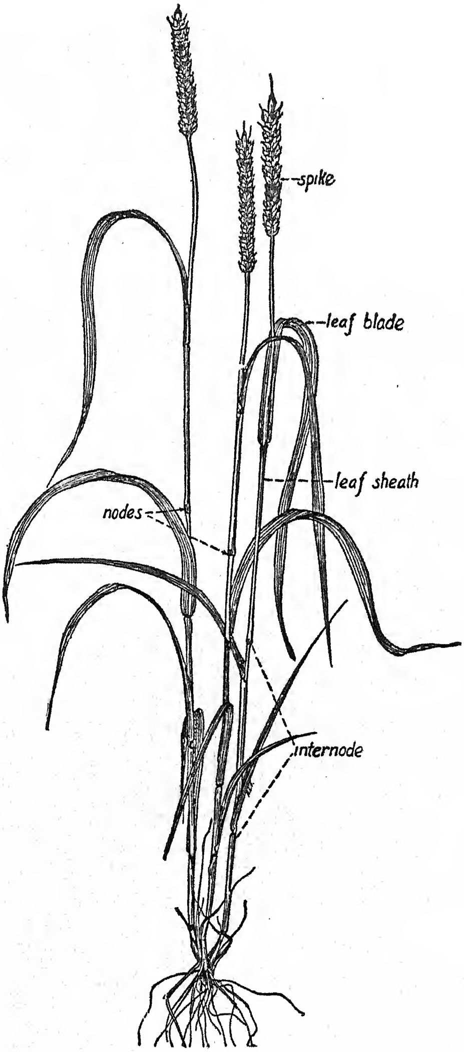

FIG. 11.—Wheat plant showing the general habit of growth of grasses. (From Robbins. in Botany of Crop Plants.)

sense, and there is tremendous variation in the form of these organs. Moreover, there are many different kinds of tissues which compose these various organs.

FIG. 12.—The Deodar Cedar, a seed plant. In this and other conifers there is a "leader"—one main stem which throughout the life of the plant holds this leadership.

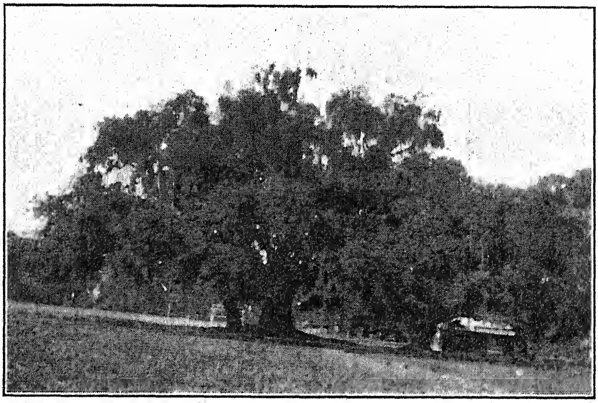

FIG. 13.—The Live Oak, a seed plant. Compare the branching habit of this plant with that of the Deodar in Fig. 12. The form of the plant body is largely determined by its branching habit.

Exercise 6. The seed-plant body. The student should take a field trip and note the different forms of seed-plant body. The various species of trees and shrubs have characteristic shapes; these may be shown well by quickly

sketching their outline. Observe not only erect forms of plants, but also climbing and creeping forms. Also note the form of plant bodies growing under different environmental conditions.

Problem 2. What is the structure of the plant cell?

If we study with the microscope the structure of plant tissues, we find them to be made up of many small bags or sacs with walls which are usually thin and transparent. Each of these microscopic sacs or compartments is called a **cell** (Fig. 14). The term "cell" was first used by Robert Hooke, an Englishman who lived from 1636 to 1703. With his improved microscope he examined all sorts of things, among them ordinary bottle cork. He observed this plant tissue to be made up of numerous compartments resembling the cells of honeycomb. So Hooke named the compartments **cells.**

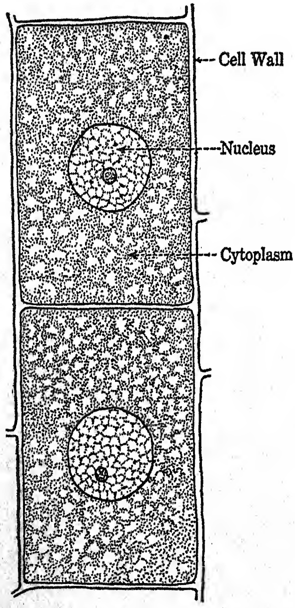

FIG. 14.—Two young cells from the growing point of a root. (From Holman and Robbins, in A Textbook of General Botany.)

Just as a brick house is made up of separate units, the bricks, so is the plant body made of separate units, the cells. **It is in the cells that all the complex physical and chemical changes of the living body go on.** Careful observation of plant cells under the microscope reveals that within each of the cells there is a quantity of a jelly-like substance. This is the living material and is called **protoplasm.** What is the literal meaning of the term protoplasm? The protoplasm of the cell is not of the same structure throughout. A denser mass of living material, the **nucleus,** is usually prominent in the cell. The nucleus is a very important part of the cell, taking an active part when the cell divides. Most important of all, the nucleus carries those determiners of characteristics which are

passed on from cell to cell, that is, from parent to offspring. In addition to the nucleus, there may be other specialized masses of protoplasm in the cell, known as **plastids**; chief of these are the green plastids (chloroplastids) which are the centers of the process of carbohydrate manufacture. All the protoplasm of the cell outside of the nucleus is called **cytoplasm.** Protoplasm is a mixture of many different chemical compounds, some of which are exceedingly complex.

In addition to the living substance the cell contains much material that is not alive. For example, every cell contains water in which are dissolved various substances that have come from the soil, and certain foods, such as sugar, which have been manufactured in the leaves. **Sap** is the name we apply to the water of the cells plus the various substances which are dissolved in it. In other words, **cell sap is a solution, in which water is the solvent.** The cell may also contain substances such as starch and protein which are not soluble in the water of the cell. The wall about the cell is not alive. It is made up of a material called **cellulose,** a substance closely related in its chemical composition to starch and sugar. Cellulose, like starch and sugar, is made up of but three elementary substances, carbon, oxygen, and hydrogen. **Cellulose is the most abundant plant substance in the world.** It is of interest to note here, in passing, that cotton, linen, hemp, and wood consist of cellulose, and that it is used as a raw material in the manufacture of such substances as artificial silk, paper, celluloid, cellophane, and guncotton. The inquiring student will want to find out how these materials, as well as many others, are manufactured from cellulose.

Exercise 7. The cells of soft tissue. Examine the soft tissues of broken leaves, vegetables, fruits, stems, etc., with a binocular dissecting microscope. It will be possible even with a magnification of 20 diameters to see that the tissues are composed of many small compartments, varying considerably in shape. These compartments are the cells. They are the units of structure.

Exercise 8. Cells in the leaf of *Elodea*, a water plant. The leaves of the water plant *Elodea* are exceedingly thin, mostly one layer of cells thick. Mount a single leaf flat in a drop of water on a slide, and cover with cover-slip. Examine with compound microscope. Compare what you see with Fig. 15. The cells are filled with green plastids (chloroplastids), which may wholly or partly obscure the more transparent nucleus. The walls are of cellulose and thin. Observe the different shapes of cells in different parts of the leaf. In fresh, young leaves, the student will observe a movement or

streaming of the protoplasm, the chloroplastids being carried along with the stream, as chips of wood in flowing water. The chloroplastids themselves are living bodies. It is in them that glucose, a sugar, is manufactured, with the aid of light. In all living cells there is a movement of the protoplasm, but in only a few plants is it rapid enough to be readily observed. What do you believe to be the advantage of this protoplasmic movement?

Exercise 9. Storage cells of the potato. Cut very thin sections of the inside white tissue of a potato tuber. Mount in water and examine with compound microscope. Observe the large, thin-walled cells, filled with starch

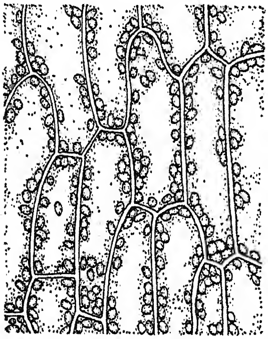

FIG. 15.—View of a portion of an Elodea leaf as seen under the high power of the microscope. The cell structure is similar to that of onion skin (Fig. 16). However, as these cells are from a green leaf, they contain chloroplasts which float in the cytoplasm. While the nucleus can be shown to be present by staining, yet it is not easily seen in the fresh material.

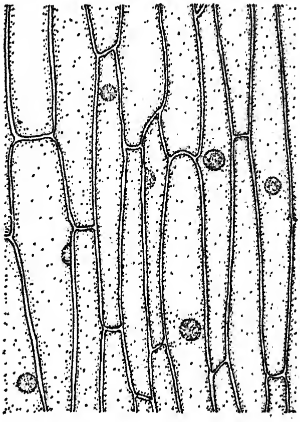

FIG. 16.—View of onion skin as it appears under the microscope. Note the well-defined cell wall. Within the cell wall there is a thin layer of cytoplasm which, together with the small disk-shaped nucleus, is made up of protoplasm, the living matter of the cell. Cell sap fills the cavity within the cytoplasm.

grains. Starch is a non-living substance—a storage product. It is of interest to know that potatoes which are mealy when cooked are those in which the cells are well filled with starch; whereas in watery potatoes starch grains do not fill the cells. Americans prefer mealy potatoes, but Frenchmen as a rule prefer the more watery sorts. Name other plants that store large amounts of starch in some part of the plant.

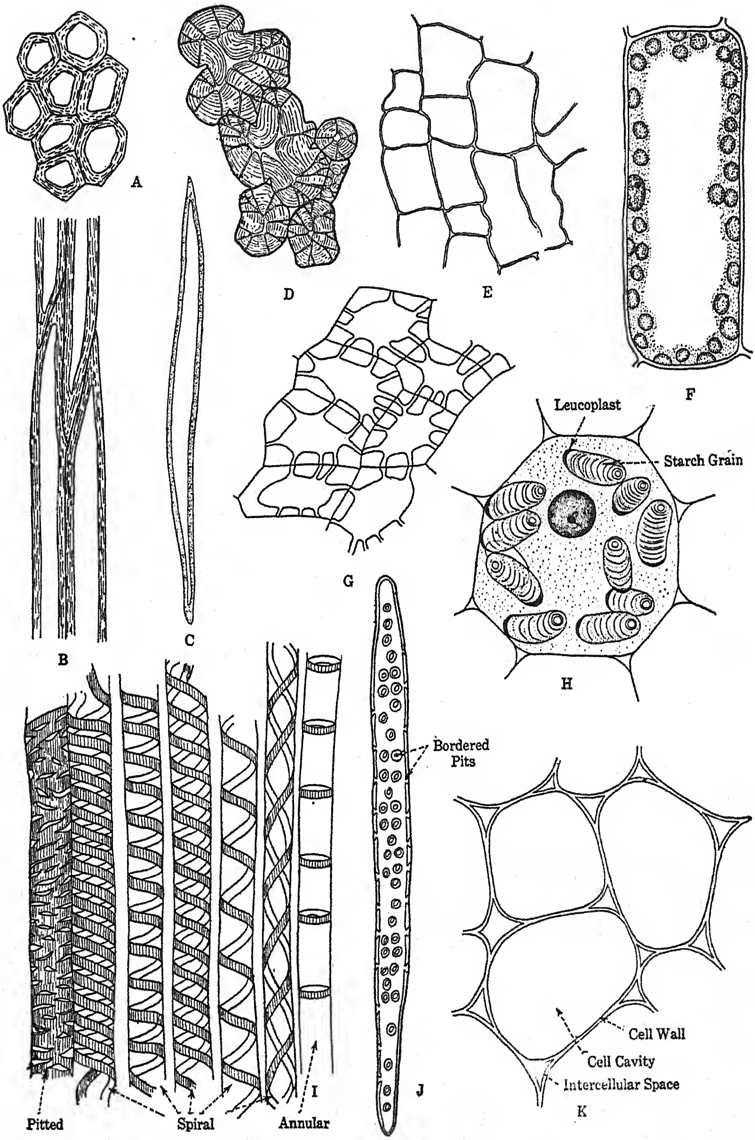

FIG. 17.—Different kinds of cells and tissues. A, fibers as seen in cross-section; B, fibers as seen in lengthwise section; C, a single fiber; D, stone cells from the shell of English walnut; E, cork cells; F, a food-manufacturing cell from a leaf; G, thick-walled pitted cells from endosperm of asparagus seed; H, starch-storing cell; I, different types of vessels; J, a simple pitted tracheid from pine wood; K, tissue made of thin-walled cells which fit loosely together. (Except A, B, C, and G, from Holman and Robbins, in A Textbook of General Botany.)

Exercise 10. Different kinds of cells. The inquiring student will be interested in examining the tissues of different organs of ordinary flowering plants, and also those of lower plants, such as algae, mosses, liverworts, ferns, etc. See Fig. 17. He will see cells differing in size, in shape, in the thickness and markings of the walls, and in the nature of their contents.

Problem 3. What is the nature of protoplasm—the living material?

In 1590, two Dutch brothers, spectacle-makers, invented the compound microscope, an instrument which was destined to become the most important tool of biological science—a tool which has made possible much of the progress in our knowledge of plants and animals, of medicine, of agriculture, of heredity.

As stated above, Robert Hooke greatly improved the microscope, and examined with great curiosity all sorts of things, among them bottle cork. Hooke saw in the cork tissue only the walls of dead cells. He had no clear idea of the cell contents. It was not until 1831 that another Englishman, Robert Brown, first recognized the importance of the nucleus in the cell, and not until 1861 that Max Schultze, a German, established the close similarity of the living substance of plants and of animals, and formulated what is known as the protoplasmic doctrine which says that **the essential part of a cell, the part which is responsible for its life, is the protoplasm.** The unit of structure and activity is really a highly organized protoplasmic mass; the wall is merely a non-living, enclosing shell. **Protoplasm has well been called the physical basis of life.**

Physical properties of protoplasm. Protoplasm is a semi-transparent, slime-like substance, much the consistency of the white of an egg. However, it does not have the same appearance throughout all parts of the cell; the **nucleus** is much denser and is darker than the cytoplasm as seen in stained cells; also there are small, dark granules embedded in the protoplasm, some of which are living; and, as we have learned, there are larger, living bodies, the **plastids,** floating in the mass of protoplasm. Sometimes these plastids contain a green pigment (chlorophyll), sometimes orange and red pigments (carotin and xanthophyll). Is it true that the green color of the vegetation of the world is due

to the pigment chlorophyll? When a cell dies the protoplasm loses its liquid consistency and coagulates, that is, sets into a more or less firm mass, like the white of an egg when it is boiled.

Exercise 11. The living protoplasm in the cells of squash and *Elodea*. Mount in water the hairs found on the stems, near the tip, of the squash plant. Under the high power of the microscope one will see, in certain cells of the hairs, a grayish, semi-transparent substance, the protoplasm. The nucleus is darker gray, and leading from it are strands or threads of cytoplasm. Cytoplasm also lines the wall of the cell. Mount fresh leaves of *Elodea*, as you did in Exercise 8, Problem 2. The cells are filled with green plastids (chloroplastids), which are embedded in a gray cytoplasm. Each plastid is a jelly-like mass of protoplasm, and dissolved within it is a pigment known as chlorophyll. See Fig. 15.

Chemical properties of protoplasm. Protoplasm appears to be a mixture of a number of different chemical compounds. It is not a single compound like sugar. We can write the chemical formula of cane sugar as follows: $C_{12}H_{22}O_{11}$; but we cannot write a chemical formula for protoplasm. The following chemical elements are always found when protoplasm is analyzed: carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, magnesium, and calcium. **There is no chemical element found in protoplasm that does not occur in the soil and air.** The compounds occurring in the mixture of compounds composing protoplasm include principally different proteins, fatty substances known as lipoids, carbohydrates, and salts. **Usually 80 per cent, by weight, or more of protoplasm is water.** Proteins rank second, by weight. The proportion of the different compounds making up the protoplasm of any cell is constantly changing. Furthermore, there appear to be significant differences between the chemical composition of the protoplasm of different kinds of plants, and of different cells of the same plant. Generally speaking, protoplasm, the living material, is a very complex mixture of chemical compounds, including among them proteins, known to be in themselves the most complex chemical compounds thus far analyzed. (Refer to *Chemical Phenomena in Life*, by Frederick Czapek, 152 pages, published by Harper and Brothers, New York.)

Physiological properties of protoplasm. Protoplasm, the living material, possesses certain properties and powers that are peculiar to it and that distinguish it from non-living material. For exam-

ple, a cell grows and develops new cells; that is, it has the power of **growth** and **reproduction.** In order to grow and reproduce, the cell must secure material from outside of itself and make that material a part of itself; that is, it must **synthesize** carbohydrates, fats, proteins, and other substances, and then change these materials into living stuff. This change of non-living stuff to living is known as **assimilation,** a change the nature of which is but poorly understood. We have come to believe that **all life comes from pre-existing life**; that is, **new cells and new organisms are derived only from existing ones.** In the processes of growth and reproduction, the protoplasm throws off waste products, that is, it has the power of **excretion.** For the building processes occurring in protoplasm, there must be a supply of energy. This the cell secures through **respiration,** another one of its peculiar processes, in which complex substances are broken down and energy liberated. Still another physiological property of protoplasm is that of **irritability.** By this we mean its ability to "sense" stimuli and respond to them. Protoplasm "perceives" light, gravity, water, and other external factors, and responds to them. Have you observed that plants in a window grow toward the light? See Fig. 128. That roots grow downward in response to gravity? That roots grow into moist soil rather than into dry soil? Protoplasm is irritable.

Suggested activities. (*a*) **Is there spontaneous origin of life?** The student should read a short account and prepare a report on how man was led, through his discoveries, to overthrow the notion that life might originate spontaneously. See one of the following: (1) Locy's *Biology and Its Makers*, (2) DeKruif's *Microbe Hunters*. (*b*) Devise an experiment to show that plants are responsive to light. (*c*) Devise another experiment demonstrating that roots respond to gravity.

Problem 4. How are cells grouped to form tissues and organs?

The cells of the plant body vary a great deal in size, in shape, in age, in the kind of material they contain, and in the nature of the work they have to do. It would take about one thousand average-sized sugar storage cells, from the root of a sugar beet, placed side by side to make an inch. Many cells of the plant are box-shaped with either square or rounded corners, others are spherical, and

still others are much longer than wide, and with pointed ends. In the growing points of the plant, as in buds and at root tips, the cells are much younger than those found farther removed from these tips.

There are cells in the plant body adapted to carry on the different kinds of work it has to do. Some are fitted to absorb water and mineral salts from the soil; others carry water, mineral salts, and foods from one part of the plant to another; others are specially fitted to manufacture food; many cells act as storage reservoirs of food; and still others are chiefly concerned with reproduction.

The cells of the plant body having special kinds of work to do are usually grouped together, forming **tissues.** These tissues are given names describing the functions or kinds of work they perform. For example, there are absorptive tissue, conductive tissue, strengthening tissue, food-making tissue, storage tissue, and reproductive tissue. An organ may be composed of several kinds of tissue. For example, a leaf possesses conductive and strengthening tissue in its veins, food-making tissue in the softer parts, and a protective tissue (epidermis) which covers the entire surface.

Thus we see that the living plant body, like the human body, is a complex structure, composed of innumerable units, **the cells,** grouped together to form **tissues,** each with a special work to do, and the tissues are in turn grouped to form the **organs** of the plant. We may picture the healthy, living plant as a marvelously constructed body, in which there is a splendid division of labor, with all cells, tissues, and organs working in harmony. We come to realize that living things resemble each other not only in gross structure and function, but also in microscopic structure.

Exercise 12. Different kinds of tissues. The student should examine thin sections of different kinds of plant materials and observe how the cells are grouped to form tissues and organs. How do cells differ in shape? Compare different tissues as to hardness, compactness, and strength.

Suggested activity. Make plasticene models of different kinds of cells.

Problem 5. What is the relation of structure and function?

The living plant expends energy and does work. If it were possible to take moving pictures of the plant at work, and to run

the film at high speed, we would see the roots twisting and turning, making their way about, and between the soil particles we would observe the young sprout of the germinating seed straining to lift the load of soil from its path; we would see parts of opening buds moving vigorously; in fact, there would be active movement throughout the plant body; and if we examined the interior of the cells, we would see the living material, the protoplasm, moving in streams from one part of the cell to the other. Plants, like animals, actually do work as long as they are alive, and this work requires a supply of energy.

The various activities or kinds of work performed by plants are spoken of as their functions. For example, absorption of water and salts from the soil, movement of materials in the plant tissues, manufacture of foods in green tissues, digestion of foods, loss of water, respiration, and reproduction are all **functions** of the plant body. Clearly, these functions are associated with certain structures. For instance, absorption of water and salts is associated with roots, loss of water chiefly with leaves, manufacture of food chiefly with leaves, etc. Furthermore, the **organs are so constructed as to carry on well the particular functions associated with them.**

Let us consider the function, photosynthesis, the manufacture of sugar in the leaf. Is the leaf structure as shown in Fig. 29 well fitted to carry on this process? In the process of photosynthesis carbon dioxide gas from the atmosphere and water from the soil are brought together in green leaf cells, and there, with the aid of light, built into a sugar, glucose. The manufacturing cells of the leaf require water, carbon dioxide gas, and light. It is obvious that a thin, flat, expanded structure, like a leaf, exposes a large surface for the absorption of both light and carbon dioxide. As concerns light absorption, the epidermis of the leaf is thin and transparent, and thus allows light to penetrate the underlying tissues; and the internal cells possess a pigment, chlorophyll, which is effective in absorbing light energy. As concerns carbon dioxide absorption, the epidermis of the leaf has numerous small openings or pores (stomata) which permit the movement inward of gases; furthermore, inside of the leaf the cells fit together very loosely, leaving large air spaces which facilitate the movement of carbon

dioxide in the leaf, allowing it to come in contact with the surfaces of almost all cells, by which it is absorbed. There is a network of fine veins in the leaf, which bring water to the food-making cells. No food-making cell is far removed from a water-conducting vein. Thus, it would appear that **the leaf is a structure well adapted to carry on the function of photosynthesis or manufacture of sugar.**

It would be possible to show how many other organs and tissues of the plant body are adapted for the specific work they perform. The relationship between structure and function is a close one. Thought on the part of the student will bring to mind many of these relationships in the plant.

Exercise 13. Relation of structure and function. Discuss the relationship between the following structures and functions: (*a*) waxy coating of leaf surface and loss of water from the leaf; (*b*) hairs on leaf surface and loss of water from leaf; (*c*) thin cellulose wall of root hair and absorption; (*d*) roots and absorption of materials from the soil; (*e*) leaf and food-manufacture.

Problem 6. What are the chemical substances found in plants?

In his study of all sorts of food and forage and medicinal plants, the scientist has made a great many chemical analyses. These analyses have told him much of the economic value of plants, of the relative importance of different parts of the same plant, and also have thrown light upon the movement of materials in the plant, and the influence of various environmental factors, such as fertilizers, upon the composition of the plant. For example, he knows from such chemical studies that some varieties of wheat are richer in protein than others, that the most starchy and valuable part of the potato tuber is the cortex or that portion just beneath the skin, that the food made use of by the opening fruit buds of orchard plants is stored in woody tissue not far removed from these buds, that an excess of nitrates as compared with carbohydrates in a tomato plant suppresses fruit development, that a deficiency of iron in the plant causes it to be pale and sickly, that sugar beets growing in a soil with a too liberal supply of nitrogen-carrying fertilizers are usually low in sugar content, and many other valuable and interesting facts about plants. There are several hundred plant chemists in the laboratories of this country.

Analyses have detected in plants no chemical elements except those found in the soil or air. That is, **there are no chemical elements peculiar to plants.** The principal elements which compose the living and non-living parts of plants are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, iron, and silicon. These are common elements found in the minerals of the soil. Of course, many more chemical elements than those listed above occur in plants. The different materials of the soil are not absorbed in equal amounts by different kinds of plants. Plants have some "selective power." We well know that if two different kinds of plants, peas and tomatoes, for example, are growing in the same soil, their mineral composition is not the same. Doesn't this show that different plants absorb materials from the soil in different proportions?

On the basis of their nutrition, plants may be grouped into (1) **the green plants,** and (2) **the non-green plants.** The green plants, which include all common crop plants, absorb mineral salts, water, and carbon dioxide, and from them make the plant foods. The non-green plants, such as bacteria, yeast, molds, mildews, rusts, smuts, and mushrooms, subsist on living or dead plants or animals and derive foods from them directly. But the foods—the materials which nourish the plant body—are the same for both plants and animals.

Considering green plants—the common plants of garden, field, orchard, and forest—we can say that the source of the chemical elements which make up their bodies is derived from the air and soil. From the air they derive carbon and oxygen; from the soil, oxygen and all other chemical elements which compose the plant.

The principal substances found in plants belong to the chemical groups known as carbohydrates, fats, and proteins. The principal carbohydrates are starch, sugars, and cellulose. **Starch** is probably the most important storage product in all plants. It is found in fruits, seeds, leaves, roots, and stems—in fact, there is scarcely a part of the plant that does not contain some starch. In most leaves, starch accumulates during the daytime, and at night is changed to sugar, which moves in solution to various parts of the plant where it is stored in some form. Starch occurs in the vascular rays of woody stems and roots, and in other tissues of these

organs. Starch is accumulated in large quantities in many seeds, such as wheat, oats, barley, beans; in certain roots such as parsnips; and in certain special types of storage stems such as potato tubers. Starch is used by the plant as a stored or reserve food. When needed for growth, it is digested, and the digested products move to growing points.

Make a list of the principal starch-storing food plants.

There are many different kinds of **sugars** in plants. The principal ones are grape sugar (glucose), cane sugar (sucrose), and fruit sugar (fructose). Glucose is considered to be the immediate product of photosynthesis, that is, of the process by which water and carbon dioxide are converted into this product. Glucose is the usual form in which carbohydrates move from one part of the plant to another part. It is found in the conducting tubes, and in the sap of most cells. It appears to be the foundation material used in the synthesis of most other plant substances. Sucrose or cane sugar is particularly abundant in the root of sugar beet and in the stems of sugar cane. Fructose or fruit sugar is particularly common in fruits.

FIG. 18.—Section through the tuber of Irish potato. The flesh of the tuber consists chiefly of large, thin-walled starch-storing cells, in which are scattered bundles of conducting tissue. A ring of vascular bundles is visible, and at the right-lower corner is an "eye."

Cellulose is a carbohydrate which enters into the structure of cell walls. It is structural material.

The **fats or oils** occur chiefly in seeds. For example, in the seed of the cotton plant there is much reserve oil. It is this oil which the seed uses as a food supply during the germination process. Make a list of plants which are the source of commercial oils.

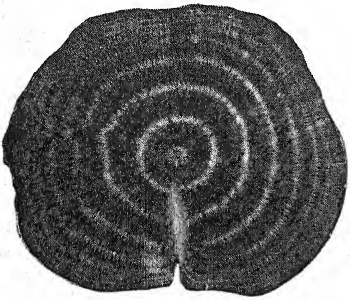

FIG. 19.—Cross-section of a sugar beet root. Observe the rings of growth, all of which are produced in one season. Most of the cells of the root are rich in sucrose (cane sugar).

Proteins are reserve foods found principally in seeds, such as beans, peas, and cereals. Protoplasm, itself, is rich in proteins.

In addition to the carbohydrates, fats, and proteins just mentioned, numerous other substances are found in plants. For example, there are the various plant pigments, resins, gums, alkaloids, organic acids, and essential oils.

As regards the chemical composition of the plant, we may summarize as follows: **The framework of the plant—that is, the walls**

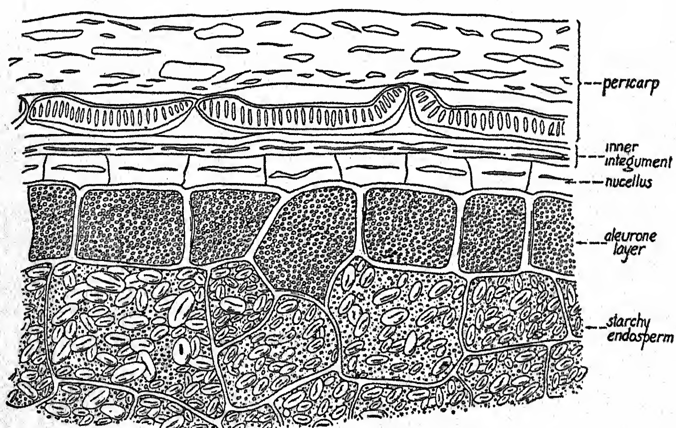

FIG. 20.—Microscopic section of wheat grain. The aleurone layer and the starchy endosperm are rich in stored food; the other layers constitute the "bran." (From Robbins, in Botany of Crop Plants.)

of all cells—is chiefly cellulose; protoplasm itself is largely a mixture of various proteins and fatty substances in water; the chief products stored in cells are sugars, starch, and proteins; and, in addition to these more common materials, there are gums, resins, alkaloids, acids, various pigments, and essential oils. The **sap of a plant is chiefly water,** carrying in solution salts derived from the soil, and various other substances manufactured by the plant.

The use of plant materials by man and animals. It is well recognized that **all animal life on the earth, including man himself, is dependent upon plants for its very existence.** Green plants are the only agencies by which the inexhaustible supply of solar energy is caught and held, and transformed into foods, for plants and animals alike. We are familiar with the fact that plants furnish us with food, clothing, shelter, and numerous drugs; that plants are used to beautify our homes and landscapes; that they supply feed for livestock; and are used in the manufacture of scores of commercial products. In Unit X there will be a more extended discussion of plants of economic importance to man.

ADDITIONAL EXERCISES AND QUESTIONS

1. What do we mean by saying that the cell is the unit of structure of the plant?
2. Enumerate the different things that protoplasm of plants can do.
3. Justify the statement that protoplasm is the most wonderful substance in the world.
4. Why do complex plants need different kinds of tissues and organs?
5. Explain why plants which live on the land have more highly developed tissues and organs than plants which live in the water.
6. Give the main characteristics of each of the four great groups of plants.
7. Upon which of the four great groups does man depend chiefly for his food supply?
8. Name as many farm crops as you can in which the root is useful to man; the leaf; the stem; the flower; the seed; the fruit.
9. Which of the four groups of plants is of least importance to man?
10. Of what importance to plants is the food stored in the seed or root?

REFERENCES

Plants Useful to Man, by W. W. Robbins and Francis Ramaley, published by P. Blakiston's Son and Company, Philadelphia, 1933. A well-illustrated book (241 figures) of 428 pages giving a discussion of the principal

food plants of the world, spices, beverage plants, medicinal plants, and industrial products of vegetable origin. "It furnishes a background of knowledge of the world's commercial plant products, both for students of botany and for those whose interests are in the fields of geography, economics, and agriculture."

The Growth of Biology, by William A. Locy, published by Henry Holt and Company, 1925. "The growth of our knowledge of living organisms is a part of the larger story of human progress; the struggles and triumphs of the human spirit. In a history of any science it is not sufficient to give an impersonal account of the discoveries as coming in a certain sequence—the human element is involved as an essential part of the story." Among other things, it includes an interesting account of the discovery of the plant cell, the development of our knowledge of protoplasm, and the structure of plants. 481 pages and 140 illustrations.

Geography of the World's Agriculture, by V. C. Finch and O. E. Baker, published by the United States Department of Agriculture, Washington, D. C. 1917. 149 pages, 206 figures. "The purpose of this study is to show the geographic origin of the world's supply of food and of other important agricultural products and to indicate briefly the climatic, soil and economic conditions that account for the distribution of the crops and livestock of the world." There are numerous maps and figures.

UNIT II

THE NUTRITION OF GREEN PLANTS

If we classify all living things on a food basis, we will have two groups. In one group there will be all **green plants**; in the other group, all animals, including man, and all plants such as bacteria, rusts, smuts, toadstools, etc., which **lack a green color.** The first group is independent; the second absolutely dependent upon the first for its food. By " independent " we mean possessing the ability to manufacture food out of such materials as the plant absorbs from the soil and air. We, as animals, just like the non-green plants, do not possess organs which enable us to take such simple materials as carbon dioxide, water, and mineral salts and make them into foods—that is, into carbohydrates, fats, and proteins. Only green plants have this power; they alone make the food, not only for themselves but also for every other living creature. The important fact for us to understand, the fact which is emphasized in this chapter, is that **the food laboratory of the world is to be found in the green plant.**

Foods—the carbohydrates, fats, and proteins—possess energy. When foods are oxidized, either in the bodies of plants or animals, that is, broken down into simpler substances, they liberate energy, and this energy is used by the living body to do work. In the building of these foods by green plants, energy is stored up. What is the source of this energy? We well know that energy can not be created or destroyed. But it can be changed from one form into another. For example, sunlight is a form of energy. We call it **solar energy. The green plant has the unique power of converting solar energy into the energy represented in foods, which is chemical energy.** This means, in short, that **all life on the earth depends upon sunlight.** The student will gain much by reading from Chapter I of Spoehr's *Photosynthesis,* published by the Chemical Catalog Company, New York. This chapter deals with

the origin of organic matter and the cosmical function of green plants.

Sunlight has been called the "prime-mover of civilization." Discuss the significance of this statement.

Some animals, like fleas, lice, and ticks, for example, gain all their food from animals. Show how, in the last analysis, they are dependent upon green plants for their food, and finally upon sunlight for their energy.

Problem 1. What is the nature of plant foods?

We are accustomed to speak of the mineral salts containing such essential elements as nitrogen, sulphur, phosporus, calcium magnesium, potassium, and iron as the "food" of plants. This statement is not strictly true. **A "food" for plant or animal is a substance that can be incorporated directly by the living cells and used as a source of energy or in making new plant substances.** The mineral salts, as such, cannot nourish the living cells any more than can nails and tacks, if taken into the human stomach. **The mineral salts are used by the plant not as a "food" but as a raw material from which foods are made.**

The foods—the substances which are capable of furnishing energy or of building tissue—**for all plants and animals are identical.** The chief foods of plants and animals are substances known chemically as carbohydrates, fats, and proteins. Well-known carbohydrates are sugars and starches. Fats occur in the liquid state ("oils") or solid state ("fats"). Proteins are the most complex, chemically, of all foods. **Carbohydrates** contain but three chemical elements; carbon, hydrogen, and oxygen; fats also contain the elements carbon, hydrogen, and oxygen, but in much different proportion from that in which they occur in carbohydrates; and proteins possess, in addition to carbon, hydrogen, and oxygen, such elements as nitrogen, phosphorus, sulphur, and others.

Exercise 14. Lists of food-storing plants. Make lists of plants which manufacture and store large amounts of each of the following foods: starch, sugar, oils, proteins.

Exercise 15. How to test for starch in plants. Cut a thin section of the potato tuber, place this on a microscope slide, and cover with a drop of iodine

in potassium iodide (0.3 gram iodine, 1.5 grams potassium iodide, 100 cc. water). Discuss results.

Exercise 16. How to test for sugars in plants. The juice of plant tissues may be pressed out and tested for sugar as follows. Prepare **Fehling's solution** thus: In bottle *A* dissolve 6.9 grams of copper sulphate crystals in 100 cc. water; in bottle *B* dissolve 34 grams of Rochelle salt (potassium sodium tartrate) and 12 grams of sodium hydroxide in 100 cc. water. Keep the two solutions *A* and *B* separate. To the plant juice to be tested add equal quantities of *A* and *B*, and heat slowly in a test tube over a Bunsen burner to boiling. A precipitation of red cuprous oxide crystals indicates the presence of glucose or other reducing sugar. Cane sugar (sucrose) does not give the Fehling's test. However, by treating cane sugar solution with a few drops of concentrated sulphuric acid, it is changed to glucose and fructose, both of which give the characteristic Fehling's test.

Exercise 17. How to test for fats in plants. Fat bodies and membranes containing fats give a characteristic red or orange color when treated with a solution of Sudan III (1 gram Sudan III crystals in 200 cc. 70 per cent alcohol).

Exercise 18. How to test for proteins in plants. Grind a soaked bean in a mortar. Place this in a test tube and add a little water. Add 5 cc. of nitric acid and heat slowly to boiling. Allow the solution to cool, pour off the acid, and add 10 cc. of ammonium hydroxide to the bean material in the tube. A deep orange color indicates the presence of protein. Test other plant materials for protein.

Is there any difference between the foods of animals and those of plants? Discuss.

What is meant when we say that a plant is " independent " or " dependent"? Name five independent plants and five dependent plants.

Suggested activity. Consult dietary charts and make a collection of foods produced by plants which are rich in carbohydrates, another of those containing large amounts of fats, and a third of those having much protein.

Problem 2. What are the raw materials used by green plants in the manufacture of food?

We have learned that **the principal foods of plants are carbohydrates, fats, and proteins.** Also, we have learned that **only green plants are capable of manufacturing foods.** It has been found by careful experimentation that the building of foods by green plants proceeds by rather definite stages. The initial process appears to be the building of a simple sugar, known as **glucose.** The fact is, this **sugar is the foundation material upon which the more complex foods, such as fats and proteins, are built.** Without this simple carbohydrate, manufactured in green cells, as a " starter," the more complex foods could not be formed.

The raw materials in the manufacture of glucose are carbon dioxide and water. Carbon dioxide comes from the atmosphere, water from the soil. **The process of manufacturing glucose from carbon dioxide and water, in the presence of light, is called photosynthesis.**

It was for a long time believed that humus (decomposed plant and animal material) in the soil was the source of carbon for plants. But if a plant is grown in pure sand, free from humus, it will increase in the weight of carbon. Moreover, it has been found by experiment that green plants placed in an atmosphere from which every trace of carbon dioxide has been removed soon cease to grow, and that green plants cultivated in a soil from which every trace of compounds containing carbon is removed thrive perfectly. It is concluded that carbon dioxide is essential to a green plant and that **the source of carbon in the plant is the carbon dioxide gas of the atmosphere.** It is useless to try "feeding" plants carbon by applying fertilizers to the soil. Carbon dioxide enters the plant through small pores in the leaf surfaces; water enters through the root hairs. These two simple chemical compounds or raw materials are brought together in those cells of the plant, chiefly leaf cells, which contain a green coloring matter (**chlorophyll**).

After the plant has manufactured glucose sugar in its green tissue, this sugar now becomes building material or basis for other foods. Part of it is converted into cellulose for the formation of the walls of new cells, and for the thickening of old walls of living cells; a portion of it is used in the production of oil; part of it is employed, together with nitrogen, sulphur, phosphorus, and other compounds of simple character, to form proteins, and part of it is oxidized in the process of respiration. The chemical elements nitrogen, sulphur, phosphorus, potassium, magnesium, calcium, and iron, all of which are indispensable, either directly or indirectly, in the building of certain plant foods, all come from the soil, occurring in the soil and entering the plant in the form of a salt. The chief salts supplying these elements are the nitrates, the phosphates, and sulphates.

Suggested activity. Prepare a paper on "mineral fertilizers." Name the chief chemical substances found in those offered by local dealers, and show

what results may be expected from the use of each, as large top growth, a green lawn, or large yield of grain.

Summarizing: **the raw materials used by green plants in the manufacture of food are (1) carbon dioxide, (2) water, and (3) mineral salts.** It will be noticed that all these substances belong to the chemical group known as inorganic. In other words, **the raw materials out of which green plants make food are inorganic compounds.** The foods belong to a group of chemicals known as organic. These are compounds which for the most part compose the bodies of plants and animals. So, **the green plant converts inorganic materials into organic**—a process peculiar to green plants alone. Also, note that, of the raw materials, water and mineral salts come from the soil and carbon dioxide from the air.

Before describing in more detail the processes in the building of foods by plants, let us find out how the raw materials—carbon dioxide, water and mineral salts—enter the plant, and how they move to the parts of the plant where they are used.

Problem 3. How do raw materials enter the plant?

Water and mineral salts are raw materials which come from the soil and enter the plant through the roots. First of all, let us find out the important facts about the different kinds of roots and their functions.

Kinds of root systems. There is much variation in the form, the spread, and the depth of the root systems of plants. Two common types of root systems are recognized. The **taproot system** is well illustrated in such plants as the beet (Fig. 21), radish, turnip, parsnip, dandelion, maple, and pine. In this there is one main root, which grows almost directly downward, giving off numerous branch roots. The **fibrous root system** is seen in its typical form in such plants as wheat, oats, corn, and other cereals. In this, one can not distinguish a main root, but there is a great number of relatively small roots of about the same size which form a network. In still another form of root system, common to many of our fruit trees, there are several large roots of about equal size which anchor the plant in the ground and which give off numerous finer branch roots.

If soil conditions are favorable, the taproot by its direct downward growth is able to penetrate the deeper layers of soil; for this reason it is adapted to dry regions. The taproot of alfalfa, for example, may extend to a depth of 10 to 12 feet, or even more.

The fibrous root system, on the other hand, is usually shallow. Fibrous-rooted plants are employed as soil binders on ditch banks,

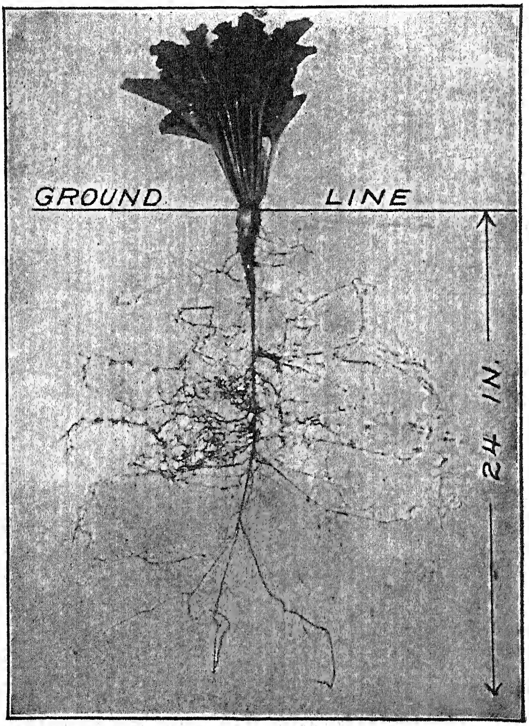

FIG. 21.—Tap-root system of young sugar beet. (From Robbins, in Botany of Crop Plants.)

steep hillsides, and in other situations where the soil is likely to be moved away by rain or wind. In the reclamation of eroded soils, fibrous-rooted plants are used extensively.

Exercise 19. Field study of root systems. Study in the field and report on the root systems of a number of common plants. Along the steep banks of streams or where erosion is rapid, one may be able to trace the root systems

of trees and shrubs. (Refer to *Root Development of Field Crops* by John E. Weaver, McGraw-Hill Book Company, New York.)

Factors which influence the growth and character of the root system. The depth and spread of the roots, although characteristic of the kind of plant, are nevertheless influenced by environmental conditions, chiefly the water content of the soil, the air supply, and the available mineral nutrients. These in turn are modified by tillage, fertilizers, crop rotation, irrigation, and drainage.

In most of our fruit plants the root systems extend as deeply in the soil as the air supply of the soil will permit, providing there is sufficient moisture. It is undoubtedly true that air supply of the soil often limits root development. It should be repeated here that all living cells must have a supply of oxygen in order to live; the root hairs and other active cells of the roots must secure most of their oxygen from the soil air which immediately surrounds them; sufficient oxygen is probably not conducted long distances through the tissues of the plant from above to below ground. The absence or scarcity of root hairs in very wet soil, and in water, can probably be attributed to poor oxygen supply. In a water-soaked soil, the air spaces are filled with water.

Excessive irrigation may produce an actual decrease in the yield of a crop, chiefly because it produces a soil condition in which aeration is faulty. It has been said that the best irrigation practice involves the most effective compromise between too much water and too little air. Why do florists use porous earthenware pots with a hole in the bottom?

Soil fertility influences the root development of a plant. It has been found that " crops grown in soil of high fertility have roots that are shorter, more branched, and more compact than those in similar but less fertile soil." Moreover, it has been shown that, where roots in their growth come in contact with a fertilized layer of soil, they not only are more branched, but they also are slow in penetrating the soil below.

Transplanting and root pruning encourage the development of branch roots. In transplanting, many root tips are injured and, as a result, branch roots are stimulated to develop. Thus, a compact root system is formed.

The extent of root systems. The extent of roots is often much greater than that of the top growth. This is true of many native species of plants and also of a number of cultivated plants. For example, in the sugar beet, the main root may extend to a depth of 5, 6, or 7 feet, and give rise to numerous branches which spread laterally several feet. Corn has a root system which may occupy as much as 200 cubic feet of soil. Weaver points out that a corn plant in the eight-leaf stage has from 8,000 to 10,000 lateral roots from the 15 to 23 main roots. A corn plant 5 weeks old, grown in a fertile, moist soil, developed a root system the absorbing area of which (excluding the root hairs) was 1.2 times as great as the area of the top, and in a dry soil 2.2 as great as the area of the top. Weaver also found that the root area of Turkey Red winter wheat exceeded that of the top by 10 to 35 per cent. The roots of common asparagus may extend to a depth of 8 or 9 feet and as far laterally, occupying the soil very completely. The roots of a

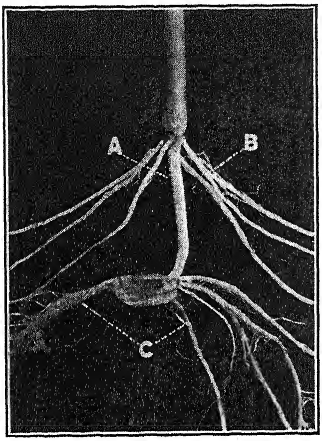

FIG. 22.—Seedling of corn. The primary or temporary roots (C), adventitious or permanent roots (B), and the stem structure (A) which may be long or short depending upon the depth at which the seed was planted.

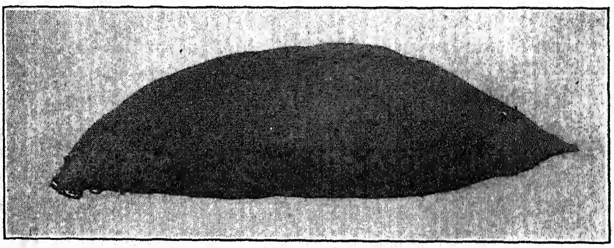

FIG. 23.—The sweet potato is a fleshy storage root.

7-year-old apple tree were known to spread horizontally more than 12 feet and to a depth of 9 feet.

Kinds of roots and their functions.

Exercise 20. Primary and secondary roots. Examine the roots of radish and wheat seedlings of various ages. Note that in each one there is, first of all, a **primary root** which develops from the radicle or rudimentary root of the embryo of the seed from which the plant grew. And in each there are small **secondary roots**, branches of the primary root. Compare older seedlings of radish and wheat. Does the primary root of the radish become the principal root throughout the life of the plant? In older seedlings of wheat, observe that numerous fibrous roots arise from the base of the young stem. These come to form the permanent root system of the wheat plant, whereas the primary roots (those from the embryo) are but temporary. The permanent roots of wheat are said to be **adventitious** (Fig. 22).

Exercise 21. Adventitious roots. Make stem cuttings of willow, geranium, or begonia; place in moist sand, and observe the position and nature of the roots which arise at the cut surface. These are adventitious roots.

Exercise 22. Prop roots. Observe the **prop roots** of corn, the clinging aerial roots of ivy, and the aerial roots of orchids.

Exercise 23. Root crops. Make a list of plants which are grown primarily for their roots.

QUESTIONS

By way of review of the studies thus far made of roots, write out answers to the following:

1. Name two kinds of roots as to origin, giving examples of each. 2. Name three kinds of roots as to the medium in which they grow, with examples of each. 3. Name four kinds of roots as to form, with examples of each. 4. Give the functions of roots, and after each function name a plant whose root performs that function. 5. From what part of the embryo does the primary root grow? 6. What is the usual direction of growth of primary root? Of secondary roots? Give advantage of each direction to the plant. 7. Name plants whose roots live but one year, others whose roots live two years, and still others whose roots live many years.

Structure of roots, and their adaptation to absorption of raw materials. Now that we have in mind the principal kinds of roots and root systems, let us inquire into their structure and how they are adapted to the intake of raw materials from the soil. We have learned that **anchorage is one of the most important functions of the roots;** also that **many roots store food**, and that a few may be used to propagate the plant. **A primary root function is absorption.**

Exercise 24. Root structure—external features. Germinate seeds of red top or blue grass by dropping the dry seeds on the surface of water in a large flat dish and keeping at room temperature for three to five days. Study the primary roots in water in a watch glass when they are ¼ to ½ inch long. Place the watch glass on the stage of a compound microscope and examine with low power to see the principal structures. Note the **root cap**, the **central conducting cylinder** surrounded by a sheath, the **cortex**, and the **root hairs.** Make a diagrammatic sketch of the root, and label all parts.

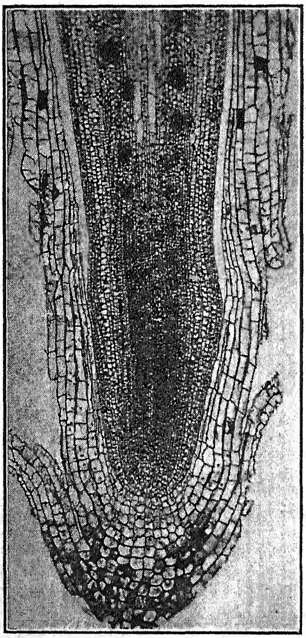

FIG. 24.—A young root tip cut lengthwise. Observe the root cap, the central conducting cylinder, and the cortex.

Exercise 25. Root structure—internal features. Mount young roots as above in water on a microscope slide, and cover with cover-slip. Examine with low power of compound microscope. Identify the parts of the root as observed in the preceding exercise. While watching, gently press on the cover-slip so as to crush the root. In the region of the central cylinder one should be able to see the vessels. These are the structures which conduct water and mineral salts up through the roots.

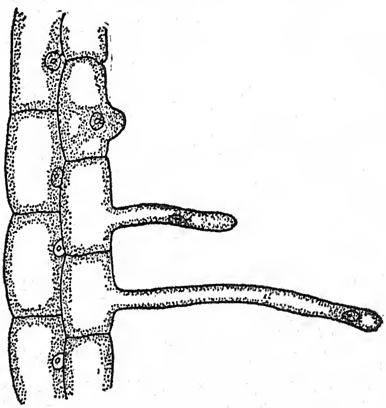

FIG. 25.—A portion of a root showing stages in the development of a root hair. A root hair is an outgrowth of an epidermal cell.

Exercise 26. Root structure as seen in cross-section. Examine prepared cross-sections of young roots. Observe the following zones or regions: (*a*) the epidermis with its root hairs; (*b*) the **cortex**, a sheath surrounding the (*c*) **central cylinder**, and within the central cylinder, strands of **phloem** and **xylem.**

Phloem possesses the structural elements which conduct foods, whereas xylem has the structural elements which conduct water and mineral salts.

Root hairs (Fig. 25). We are familiar with the fact that, in ordinary land plants, the very important work of absorbing water and mineral nutrients from the soil is confined to the roots. But **not all root surfaces can absorb.** On the slender, thread-like roots are innumerable outgrowths, the root hairs, and these are the principal absorbing organs. In some plants it is almost impossible to see them without a magnifying lens. However, they may stand so thickly on the fine roots as to form a white fuzzy growth. The younger parts of the very fine rootlets which have not become corked over absorb to a limited extent; but **in the majority of plants by far the greatest amount of absorption is carried on by the root hairs.** Even the fine rootlets soon become covered with a corky layer which is impervious to water.

Transplanting destroys root hairs. If a plant is transplanted or disturbed in cultivation or at thinning, it wilts. We may see no apparent injury to the roots. However, on closer examination we observe that the root hairs have had their connection with the soil particles broken, and that many of the finest rootlets bearing root hairs are destroyed. The plant does not recover until new root hairs are developed.

It is well known that it is dangerous to transplant young trees, shrubs, or vines when they are clothed with leaves and are actively growing. In this condition the plant demands more water than when in a dormant state. If the fine rootlets and root hairs are destroyed, as is largely unavoidable during transplanting, the demands for water are greater than the roots can supply. Excessive watering will not make up for the loss of roots and root hairs by trees, shrubs, and vines transplanted during the growing season. The roots may be surrounded by nearly saturated soil, but in the absence of root hairs, they can not absorb adequate amounts of water. In transplanting it is the usual practice to reduce the water-losing area (leaf surface) by pruning.

Exercise 27. Relation of root hairs to soil particles. Carefully remove seedlings growing in fine sand. Observe the relation of root hairs to soil particles. (Fig. 26.)

The soft, delicate root hairs, in growing, wrap themselves about and spread over the soil particles coming in very close contact with them. Thus, they expose a maximum surface to the particles, from which they absorb both water and mineral salts. In a soil that is well drained and contains the proper amount of moisture, the water occurs as very thin films and as wedge-shaped masses at the points of contact of the soil particles, and in this water the various mineral salts are dissolved. Consequently, by growing about the particles the roots place themselves in the best position for getting water and salts.

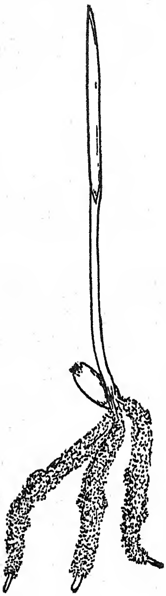

FIG. 26.—Wheat seedling showing soil particles clinging to root hairs; note that the root cap is free of root hairs. (From Robbins, in Botany of Crop Plants.)

Root hairs increase the absorbing surface of a plant. A plant with hundreds of thousands of root hairs on its fine rootlets has a tremendous total absorbing surface. The fine rootlets alone, without the root hairs, would have a relatively small total surface. It has been computed that a corn plant with root hairs has an absorbing surface of about 6 times that of one from which the root hairs have been removed.

Duration of root hairs. Root hairs have a very short life. As the rootlet upon which they grow pushes its way through the soil by growth at the tip, new root hairs are continually formed just behind the tip, and the oldest root hairs farther back are constantly dying off. Any one individual root hair lives only a day or so. Thus there is a constant new supply of rapidly growing root hairs. Moreover, the roots are continually exploring new soil regions.

Exercise 28. The structure of the root hairs. Study the structure of root hairs with a compound microscope. Note that each root hair is a tube-shaped body, growing out from an epidermal cell of the rootlet. In fact, each root hair is a single plant cell with the power to carry on the various life

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processes. It is a living structure. The living material and the cell sap are surrounded by a non-living wall. The wall is lined on the inside with a very thin membrane of living material, the **protoplasmic membrane**. This membrane is an extremely important part of the cell, as we shall see later. Make a drawing of a root hair and several bordering cells.

Substances from the soil enter the plant chiefly through the root hairs. It should be emphasized that **almost all materials which enter the plant from the soil must pass through the wall and living membrane-lining of the root hair.** From the root hair, the absorbed materials are passed on to the other root cells, and from them, into conducting tubes and thence to various parts of the plant.

It used to be thought that plants " suck up " tiny particles of soil, and " feed " upon them. It is now known that **the plant is incapable of absorbing solid particles. All materials taken in by the plant from the soil must be in a liquid state, that is, they must be in solution.** Otherwise, they cannot pass, or diffuse, through the root-hair wall and the living membrane which lines it.

Give the structural features of a root which fit it to the process of absorption. What is the function of the root cap? Compare soil roots with roots of water plants, and also with the air roots of an orchid. Explain the differences. How do root hairs differ from rootlets in structure and in place of origin? Do root hairs become rootlets?

The process of absorption. The principal point to keep in mind in connection with absorption by roots is that **all substances which enter the root hairs from the soil must be in solution.** Water is the solvent. The second important point is that all substances which pass from the soil to the inside of the root hair must pass through the cell wall of the root hair and also the living, protoplasmic membrane which lines the wall. Several simple experiments should first be performed by the student so that he will better understand the process of absorption.

Exercise 29. Diffusion. In the bottom of a beaker or glass tumbler of water place a few crystals of copper sulphate (blue vitriol). If the vessel is not disturbed, the copper sulphate goes gradually into solution. At first the solution is a deeper blue in the neighborhood of the crystals, the color being less and less blue as the distance from the crystals increases. This indicates

that particles (molecules) of copper sulphate are gradually moving out into the water. After a long time, the whole solution becomes a uniform blue color, indicating the equal distribution of copper sulphate molecules throughout. In the solution there are two components, water and copper sulphate. Water is the **solvent**, copper sulphate the **solute**. In this experiment the movement of copper sulphate molecules into the water from a region where they are in greater concentration to one where they are in less concentration, and the movement of water molecules into the copper sulphate from a region where they are in greater concentration to one where they are in less concentration, illustrate **diffusion**. Keep in mind that diffusion plays a most important part in the absorption of materials by the roots.

Exercise 30. Diffusion through membranes. In the preceding experiment, the two substances, water and copper sulphate, were not separated by any kind of a membrane. Now let us devise an experiment which resembles, in part at least, the situation represented in the root hair. Recall that the sap in the root hair is separated from the soil solution by two membranes: (1) the **cell wall**, composed of non-living matter called cellulose; and (2) the living **protoplasmic membrane**. The two membranes have very significant differences in their behavior.

With a carpenter's 1-inch bit, drill a smooth hole down into the middle of a fresh carrot, being careful that the bit does not cut through the surface at any point. Connect a one-hole No. 6 rubber stopper to the end of a 5-foot length of glass tubing of small diameter. Pour corn syrup into the carrot, and fit the stopper into the hole so that the syrup extends into the glass tubing to a point above the stopper. Support the carrot in a jar of water so that the surface of the water is on a level with the surface of the syrup in the tube. After a time you will observe that the liquid in the tube has risen. We are forced to the conclusion that more material passed into the sugar solution than passed out of it. Both kinds of membranes are present in the shell of carrot surrounding the sugar solution. The living protoplasmic membranes of the carrot are semi-permeable. That is, they allow some substances to pass through them more readily than others. In this case the sugar molecules pass through the membrane only slowly, if at all, and since there is a relatively greater concentration of water molecules on the outside than in the syrup on the inside the more rapid diffusion of water is toward the inside.

The protoplasmic membrane of a root hair is a semi-permeable membrane. The cell wall is wholly permeable, that is, does not inhibit the movements of any kind of molecules through it. Consequently, in the movement of materials into the root hair, the cell wall can be disregarded. The root-hair sap is a solution containing not only sugar and other organic compounds, but also a number of different salts, all in solution in water. The soil solution contains many different mineral salts in aqueous solution. These two

solutions—that of the root-hair sap and that of the soil—are separated by a semi-permeable membrane, the protoplasmic membrane, which does not allow all substances to move through it with equal ease and speed.

Under natural conditions, the cell sap of the root hair is always more concentrated than the soil solution; that is, the water molecules are in less concentration inside the root hair than outside. We learned from the foregoing experiment that water passed from the region where the water molecules are more concentrated into a region where they are less concentrated. Apply this to the movement of water from the soil into the root hair.

Exercise 31. Plasmolysis. This experiment throws further light on the movement of substances through semi-permeable membranes. Immerse whole fresh leaves of the water plant *Elodea* into a strong solution of ordinary table salt or sugar. The solution can be added to the leaf on a microscope slide, covered with cover-slip, and observed with the high-power compound microscope. After a while it will be noticed that the contents of the leaf cells are shrinking, and pulling away from the wall. This shrinking, known as plasmolysis, is due to the withdrawal of water from the cells by the solution outside. Water continues to move out of the cell just as long as the solution outside is more concentrated than that in the cell. In the plasmolyzed cell what solution is between the cell wall and the protoplasmic membrane?

Exercise 32. Turgidity of cells. The swollen state of cells is called turgidity. We know that the crispness of the leaves and the rigidity of the young parts of plants is due to the turgid condition of the many hundreds of thousands of individual cells which compose it. We can understand this behavior better if we consider the following exercise. When slices of potato are placed in water, they remain rigid. All cells are well filled with water, and as a result are swollen. The combined effect is a turgid slice. If, on the other hand, the slices of potato are placed in a strong salt or sugar solution, they soon become limp and flexible; all cells lose water; it passes from them into the strong solution outside where water molecules are in less concentration. As a result, each cell is like a partially deflated automobile tire, and the whole slice is of the same character. It is not so much the nature of the substance as its concentration which determines the movement of water in or out of the cell. For example if the slices of potato are put in a salt or sugar solution, the strength (concentration) of which is less than that of the sap in the potato cells, they will remain fresh; instead of losing water they will absorb it. The cells of the slices will lose water only when the strength of the solution in which they are immersed is greater than that of the solution in them, that is, when the water molecules are in greater concentration inside the cells. **Water tends to move from a solution of low concentration to one of higher concentration.** In most

agricultural lands, the soil solution has a lower concentration than has the solutions in the plant. Consequently, the movement of water is from the soil to the plant.

The normal, active root hair is swollen and distended like an automobile tire inflated with air. It is filled with water, various mineral salts in solution, and other substances, all of which render it swollen. It does its best work only in this distended condition. If, through lack of water, the plant wilts, the root hairs, as well as other cells of the plants, collapse to a certain extent, and in this state, they do not perform their work properly. **Any part of a plant in a wilted condition is incapable of making growth.** It may remain alive and be able to recover if given water, but it will not grow. Withholding water from a plant to the extent of causing prolonged wilting cannot fail to retard its growth.

Conditions which influence the rate of absorption. Several conditions have a marked influence upon the rate of water absorption by root hairs. In the first place, when the amount of moisture in the soil reaches a low point, the rate at which it is absorbed by the roots is diminished. There are forces in the soil which hold the water, and unless the forces of absorption exceed these soil forces, water will not be taken in by the roots.

The temperature of the soil is another important factor determining the rate of water intake. The rate is decreased by lowering the temperature, and most plants cease to absorb at or slightly above freezing. Place a small potted plant in a dish of ice water, and another in water of room temperature. After a time note results. Explain.

The air supply of the soil also influences the absorption rate. **Root hairs do their best work only when they are well supplied with air.** In soil that is compacted, or so wet that air is excluded from the soil spaces, absorption is slowed down.

The strength or concentration of the soil solution is a very important condition determining the rate at which water from the soil enters the plant. **Normally, the solution in the root hair is of greater concentration than that in the soil.** Under this condition, water moves into the hair through the living membrane which separates the two solutions. If, on the other hand, the soil solution should become more highly concentrated than that in the

root hair, water would move from the root hair to the soil, and a wilting of the root and entire plant would follow. In an alkali soil, the soil solution surrounding the root hairs is often quite concentrated; at times its strength may approach that of the sap of the root hairs; under these conditions, water movement inward is slow, and the plant finds it difficult to take in as much water from the soil as it loses through the leaves to the air. **Water continues to move inward as long as the concentration of the solution inside of the root hair exceeds that of the solution in the soil on the outside.** In other words, if the cell sap be denser than the soil solution, that is, poorer in water, water will be absorbed from the soil solution.

It is well known that grass, weeds, and other plants can be killed by drenching the soil in which they are growing with a strong salt solution. In this case the plant is killed by a failure to absorb sufficient water or by an actual loss of water, rather than poisoned by the chemical. The root hairs, being surrounded by a soil solution which has a greater concentration than that of the root-hair sap, die because water is withdrawn from them. Soon the entire plant dies, for it continues to lose water through its leaves, while at the same time absorption of water is stopped.

The rate of water absorption is also increased if the rate of water loss from the leaves is increased, providing there is an ample supply of soil water to draw upon.

The movement inward of any particular salt appears to depend chiefly upon the available supply in the soil and the rate at which it is used in the plant. The essential elements which are absorbed by the plant are soon changed into new substances, and so their concentration in the plant is kept constantly less than that in the soil solution.

Enumerate the factors which influence the rate of water absorption by plants.

Most substances in the root are not lost to the soil. It should be pointed out that, whereas substances pass from the soil through the root-hair membrane into the root, most substances in the root hairs are unable to pass back into the soil. Carbon dioxide, in the ordinary process of respiration of root cells, continually passes from the roots to the soil; and, under certain conditions,

water also may be lost to the soil. It has been thought by some that under certain circumstances sugar in the sugar-beet root passed from the root into the soil. This is not the case. The percentage of sugar in the root may go up and down as a result of different amounts of water in the beet, but the actual ounces of sugar in the root do not become less, except under very unusual circumstances when the stored supply is called upon to make an abundance of new leaf growth.

Summary. We may summarize our discussion of the nutrition of green plants thus far as follows: (1) The foods of plants, as well as those of animals, are organic, and chiefly carbohydrates, fats, and proteins. (2) These foods are built in the plant body, utilizing as raw materials carbon dioxide (from the air) and water and mineral salts (from the soil). (3) Water and mineral salts are absorbed from the soil by the roots, which are structures well adapted to the process of absorption.

QUESTIONS

1. Define solute, solvent, solution.
2. Why is it necessary to understand diffusion in order to study the process of absorption by roots?
3. Explain why plants growing in cold bogs have difficulty in absorbing water.
4. In what ways are alkali soils injurious to plants?
5. What is meant by the "selective power" of root hairs?
6. When slices of red garden beets are washed, and then placed in fresh cold water, the water does not become red. But when slices of such beets are boiled, the water soon becomes red. Explain.
7. Why do young plants become limp when they wilt?
8. Why does a dried prune swell when placed in water?
9. Why is it possible to kill Canada thistles or other perennial weeds by the use of a liberal application of salt to the soil?
10. Is it possible for a grower to injure or kill plants by applying to them too much mineral fertilizer? Explain.
11. Explain why corn on land which has been flooded loses its green color and turns yellow.

Types of leaves. We now have to consider the intake of carbon dioxide, and the plant structures (leaves) chiefly concerned in this process.

Exercise 33. Types of leaves. The student should collect and bring into the laboratory a considerable variety of leaves and have them before him while reading the following paragraphs. A suggested list is as follows: oak, maple, rose, clover, pea, cherry, ash, locust, horse-chestnut, strawberry, corn, iris, lily-of-the-valley.

All common leaves have a broad, thin **blade**, which is covered above and below by a thin, transparent epidermis (Fig. 28). The blade has two portions, the **veins**, and the soft green tissue known as **mesophyll** supported by the veins. Look up the literal meaning of the word mesophyll. Most leaves have a **stalk** or **petiole** which attaches the blade to the stem, and through which materials are conducted to and from the blade. Some leaves, such as those of grasses and lilies, have no petioles, and are said to be **sessile** (meaning, sitting). Some leaves also have a pair of leaf-like outgrowths at the leaf base where it joins the stem. These are known as **stipules**.

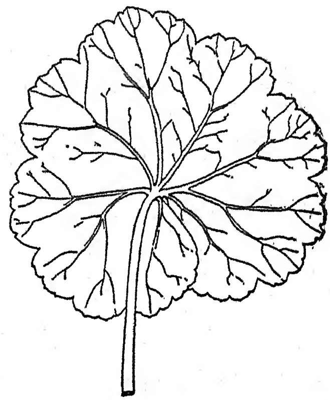

FIG. 27.—Drawing of the blade and a portion of the petiole of a geranium leaf. Note the palmately-arranged veins which radiate out from the point of attachment of the petiole. Explain the roles of the petiole, the veins, and of the thin, expanded blade.

The arrangement of veins in a leaf is spoken of as **venation**. This varies in different kinds of leaves. For example, in grasses, lilies, iris, etc., the veins that are easily seen run parallel to each other the full length of the blade. This is known as **parallel venation**. In most broad-leaved trees and shrubs, also in many herbs, the veins that are easily seen branch frequently and join again, so that they form a network. This is known as **net venation**. In many leaves with net venation there is a single **midrib** or primary vein, from which the smaller veins extend, somewhat like the divisions of a feather. Such leaves are said to be **pinnately veined**. In other plants there may be several principal veins spreading out from the upper end of the petiole. Such leaves are **palmately veined**.

Leaves vary greatly in form. A **simple** leaf (Fig. 27) has a single blade, either with or without a petiole, or stipules. A **compound** leaf has a leaf blade consisting of a number of separate leaf-like parts, called **leaflets.** How can you tell a leaf from a leaflet?

Leaves also vary in size, in shape, in nature of the margin, in kind of lobing, in number of leaflets, and in many other characters. In fact, there are hundreds of terms descriptive of leaves.

Exercise 34. Terms describing leaves. Using the following form, check off in the proper columns the terms descriptive of some 20 different kinds of leaves collected by you.

Name of plant	Simple	Compound	Petiolate	Sessile	Parallel venation	Netted venation	Pinnately veined	Palmately veined

Exercise 35. Types of leaves. Make accurate sketches of the following and label the parts:

1. Simple pinnate leaf.
2. Simple palmate leaf.
3. Compound pinnate leaf.
4. Compound palmate leaf.
5. Parallel-veined leaf.

Structure of leaves and their adaptation to absorption of carbon dioxide. We have seen that the leaf blade is a thin, flat structure which exposes a large amount of tissue to the gases of the atmosphere. In this particular it would appear to be adapted to absorption of carbon dioxide. But let us examine the microscopic structure of the leaf and see if in any other ways it is adapted to this purpose.

Exercise 36. Leaf structure. With binocular dissecting microscope, using 20 to 50 magnifications and strong illumination, both transmitted and reflected, examine both surfaces of a number of different kinds of leaves,

noting form of epidermal cells, stomata, epidermal hairs, and other gross characters. The leaves of *Tradescantia* (Wandering Jew) have very large stomata.

Exercise 37. Epidermis of leaves. Strip pieces of the epidermis from the lower and upper surfaces of some leaf, such as *Tradescantia.* Mount these with outer surface up, and examine with compound microscope. Are the stomata equally numerous on both surfaces? Are epidermal cells transparent? Make a drawing of several stomata and 4 to 8 epidermal cells adjoining. Label. See Fig. 28.

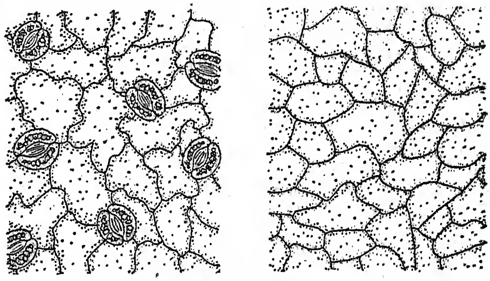

FIG. 28.—At right, the upper epidermis of a geranium leaf is shown. A portion of the lower epidermis of the same leaf is shown at left. Both are made up of irregularly shaped cells. Bean-shaped cells, the guard cells, which fit together in such a way as to leave a slit, a stoma, between each pair are seen at left. Why are stomata usually found only on the under side of the leaf?

Thus we see that, in addition to the great surface exposed by leaves, there are openings in the epidermis through which carbon dioxide and other gases may pass in. Now, let us examine the internal structure of the leaf. For this purpose we need thin cross-sections of the leaf.

Exercise 38. Anatomy of leaf. Examine with compound microscope prepared cross-section of some leaf. Compare with Fig. 29. Note the (1) epidermal coverings, upper and lower; (2) the **stomata** with their **guard cells;** (3) the mass of green tissue between the epidermal layers, known as **mesophyll;** (4) the **veins;** and (5) large **air spaces** between the mesophyll cells. Make a diagram of the leaf as seen in cross-section, labeling all parts. From your observation of the slide, answer the following questions: (1) How do guard cells differ from other epidermal cells? (2) Is it possible for carbon dioxide which may come through stomata to diffuse throughout the leaf and come in contact with even the innermost cells? (3) Do you think that the leaf structure is such as to adapt it to absorption of carbon dioxide? Why?

From our study of the leaf, we see that it has three kinds of tissue: (1) the **epidermis**, (2) the **mesophyll**, and (3) the **veins.** In the epidermis are stomata, each with two **guard cells.** These

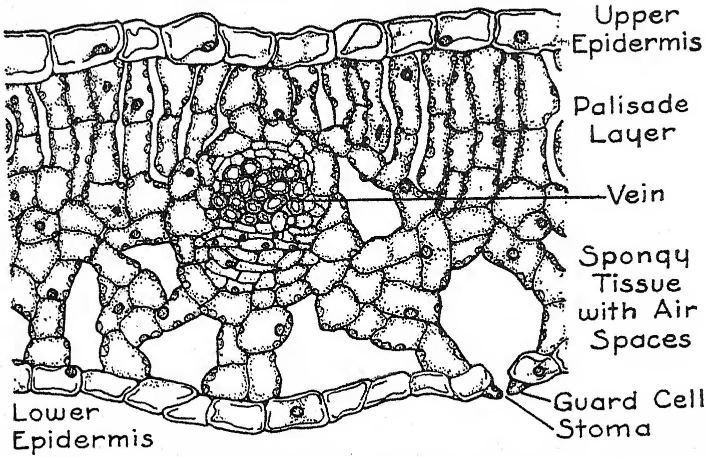

FIG. 29.—Cross-section of a typical leaf, showing its internal structure.

change their shape, so that the stoma may be closed or open. Further on in our study of water loss from the plant we shall have more to say about stomatal movement. The mesophyll is composed of two kinds of tissue (Fig. 29): (1) the **palisade parenchyma**, and (2) the **spongy parenchyma.** Palisade parenchyma cells have their long axes at right angles to the leaf surface. There may be one to several layers. Spongy parenchyma usually forms somewhat more than half of the mesophyll. The cells are not elongated. Certain parenchyma cells may form a single-layered sheath surrounding the veins. All cells of the palisade parenchyma, all cells of the spongy parenchyma, except in certain plants those which

FIG. 30.—This leaf has been treated with a caustic soda solution to destroy the soft leaf tissue, thus making readily visible the frame-work of veins. These veins not only support the soft food-making tissue, but they carry materials.

surround the veins, and guard cells are abundantly supplied with chloroplasts. These possess a green pigment known as **chlorophyll.** The chloroplasts, by virtue of their chlorophyll, play a most important part in the manufacture of food by the plant.

The process of carbon dioxide intake. Only about 3 to 4 parts in 10,000 of the atmosphere is carbon dioxide. There appears to be nothing to prevent the diffusion of the gases of the atmosphere, including carbon dioxide, through the stomata, and into the intercellular spaces of the mesophyll tissue. We know that carbon dioxide gas is soluble in water, and that the walls of mesophyll cells are wet. Therefore, the surface film of water on the outside of mesophyll cells contains a quantity of carbon dioxide in solution. In the diffusion of carbon dioxide, just like that of copper sulphate described in a previous exercise, **the molecules move from a point where there are many of them to a point where there are fewer of them.** Therefore, if carbon dioxide is being used up in the mesophyll cells, that which is in solution on the surface film of water readily diffuses through the wall and protoplasmic membrane, and comes into contact with the cell contents. As a matter of fact, carbon dioxide gas diffuses into the chloroplasts.

Problem 4. How do raw materials move in the plant?

We have discussed the movement of the raw materials used by the green plant in the manufacture of food into the plant from the outside world—how water and mineral salts enter the roots, and how carbon dioxide enters the leaves. These **raw materials are made into food chiefly in cells that are green, that is, contain chlorophyll. The leaves are the chief food-making organs of the plant.** Consequently, it will be necessary that we explain how water and mineral salts, once they are in the root hairs, move from the root hairs to the leaves. In order to explain this movement, we should know something of the structure of stems as well as of roots, for it is in them that the materials move to the leaves.

Types of stems. We are familiar with the different kinds of common stems. For example, there are stems of the **woody type,** represented by the trees and shrubs, and stems of the **herbaceous type,** represented by the many thousands of different kinds of

annual plants. **Herbs** have comparatively little hard, woody tissue.

Exercise 39. Types of stems. Make a list of ten plants of **woody** type and another of ten of the **herbaceous** type.

As to form, we recognize three common types of stems, namely, **erect**, **prostrate**, and **climbing**. The majority of plants have erect stems. The student can readily name many among herbs as well as among trees. Such plants as cucumber, squash, field morning-glory, and strawberry have prostrate stems. Examples of plants which climb upon other plants and depend upon them for mechanical support are grape, woodbine, hop, and scarlet runner bean.

It is obvious that one of the chief functions of all stems, in addition to that of conduction of materials, is to support the leaves, raising them into the light and air. But many stems are also food-storage organs. For example, in the stems of all trees and shrubs, large amounts of food are stored. Also, many plants have stems underground, as well as above ground, and such stems are usually storehouses for food. Examples of such are the **tubers** of Irish potato, the **bulbs** of onion and *Narcissus*, the **corm** of gladiolus, and the **rhizome** of Solomon's seal, of Canada thistle, of field morning-glory, and many other plants. Of these we will speak in another unit.

Structure of stems. Simple water plants have little need for conducting tissue, for the plants are surrounded on all sides by water, containing in solution the various mineral salts necessary for plant life. Likewise those plants which grow close to moist soil, such as mosses and liverworts, do not require an extensive conducting tissue. But in land plants, with their leaves raised into the air, and with a great amount of tissue far distant from the source of water and mineral salts, there is need for an efficient means of conducting these materials throughout the plant.

In our study of the structure of stems, let us take three different cases: (1) the herbaceous stem of sunflower, (2) the woody stem of box elder, or cottonwood, or other common broad-leaved tree, (3) the stem of corn.

Exercise 40. The structure of the herbaceous stem of sunflower. Examine prepared cross-sections and lengthwise sections. Observe the following parts:

(1) **epidermis,** a single layer of cells which protect the underlying tissues from drying out and from mechanical injury; (2) the **cortex,** composed chiefly of **parenchyma** tissue, also **fiber** groups, and just beneath the epidermis, a tissue with thickenings in the cell corners, known as **collenchyma;** (3) the **vascular bundles,** each with an outer region, the **phloem,** an inner more woody region, the **xylem,** and between them a growing tissue, the **cambium;** (4) central **pith;** and (5) broad **vascular rays** extending between the vascular bundles. Make a large diagram of the cross-section showing the relationship of stem regions, without showing cellular detail. Label. Compare the appearance of the different tissues as seen in cross- and lengthwise sections.

Exercise 41. Structure of a woody stem. Study cross- and lengthwise sections of a one-year-old woody stem (Fig. 31). Note three distinct regions: the **bark,** the **wood,** and the **pith.** The bark may be peeled away from the wood. It separates from the wood along a region known as the **cambium.** The outer part of the bark is a layer of **cork,** beneath which are several layers of cells containing chlorophyll. The inner part of the bark is the **phloem.** In the woody part of the stem note the **vascular rays,** radiating from the **pith.** Make a diagram of the cross-section, labeling all parts.

Exercise 42. Structure of the corn stem. Study prepared cross-sections. Observe the **epidermis,** the **cortex,** and a large number of vascular bundles scattered in **parenchyma tissue.** Make a diagram, labeling all parts.

Before studying in greater detail the structure of the stem, let us perform an experiment which will demonstrate in which tissues of the stem water moves.

Exercise 43. To find out through what region water rises in stems. Place a fresh, leafy twig with the cut end in a solution of eosin. After several hours, cut sections at intervals along the stem and observe the course the liquid has taken. Repeat the experiment, using some herbaceous stem. Are the veins stained red? In another experiment remove a ring of bark from a leafy twig, and place the cut end, below the girdle, in water. Do the leaves wilt? From these experiments, what is your conclusion as to the tissues in which water is carried?

Exercise 44. Structure of vascular bundles. Study once more the stem slides of Exercises 40, 41, and 42, paying particular attention to the vascular bundles. Observe that the bundles of sunflower and the woody stem have a cambium between the phloem and xylem, whereas there is no cambium in the vascular bundles of corn. The principal structural elements of the xylem are the vessels in which water and mineral salts are conducted, **wood fibers** which give strength and support, and **wood parenchyma,** a tissue which stores food. The principal structural elements of the phloem are the **sieve tubes** in which foods move, **companion cells** adjoining the sieve tubes, **phloem fibers,** and **phloem parenchyma.** Make a drawing of a single vascular bundle of corn or sunflower as seen under the high power of the compound microscope. Label.

You will remember from your study of root structure that there is a **central cylinder** in which vascular tissue is found, a **cortex,** sur-

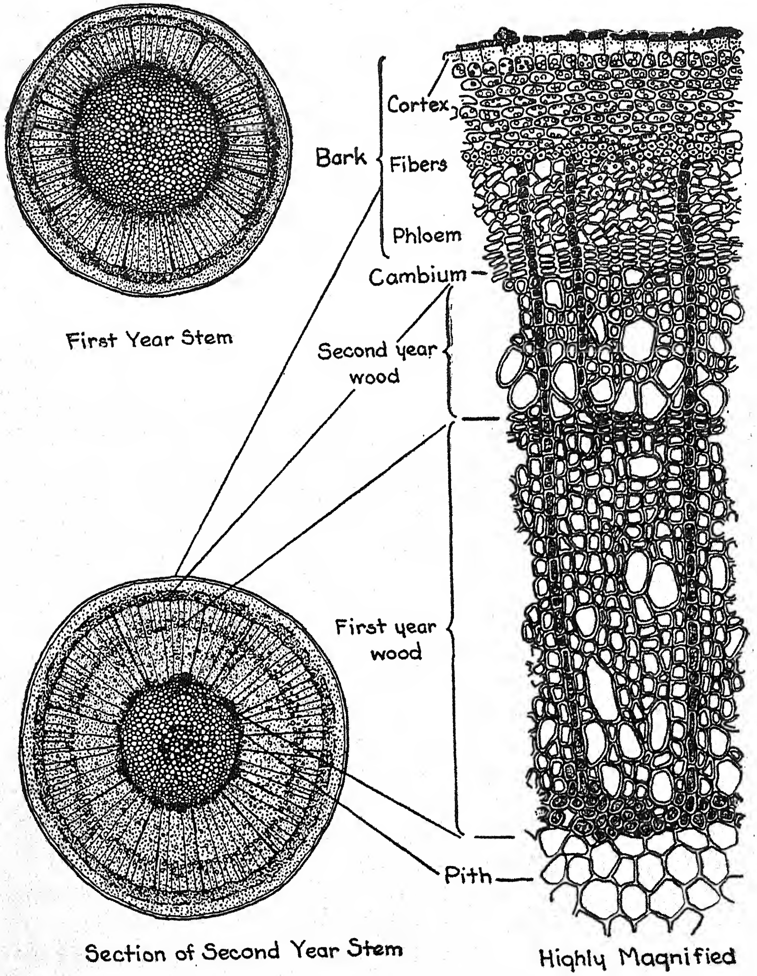

FIG. 31.—Growth in diameter of a stem of box elder. Sections made June 25, 1934, at different points of the same branch. After studying the diagram in connection with the description in the context of how growth in diameter of stems takes place, you should be able to answer the following questions: At what place in the stem are new elements of wood and new elements of bark added? How can a cambium cell form a xylem vessel in the wood? How can a cambium cell form a phloem (sieve) tube in the bark? What makes it possible to tell from the section where growth ended in the wood at the end of the growing season of 1933? How can you tell where growth in diameter began in 1934? Why is the 1933 layer of wood thicker than the 1934 layer? Why is the bark in a two-year-old stem thicker than that of a one-year-old stem?

rounding the central cylinder, and an **epidermis**, including root hairs. These structures of the root connect corresponding structures in the stem. After water has moved into the root hairs, it proceeds by diffusion from root-hair cells to adjacent cortex cells, and by the same process from one cortex cell to another until it reaches the vessels in the xylem of the vascular region. In the vessels it moves rapidly upward through the root into the stem, and thence on upward in the vessels of the stem to the leaves. **The veins of the leaves are vascular bundles,** and they are directly continuous with the vascular bundles of the stem. So that water and mineral salts move out through the petiole of the leaf into all the veins. From the veins, these raw materials diffuse outward into mesophyll cells.

Exercise 45. Leaf veins. (Fig. 30.) Treat small thin leaves with warm 80 per cent alcohol until the chlorophyll is gone. Place in a shallow dish of water, and examine with high magnification of binocular dissecting microscope. Observe the network of veins, and the vein endings. Picture to yourself the movement of raw materials outward in these small veins, and their diffusion into adjoining mesophyll cells.

The process of movement of raw materials in the plant. In the last paragraph we have given the path of movement of water and mineral salts from the soil to the mesophyll cells of the leaf. This path briefly is as follows: soil—root hair—cortex—vessels of root—vessels of stem—vessels of leaf petiole—vessels and tracheids of leaf veins—mesophyll cells of leaf.

What are the forces concerned in the movement of a body of water upward in the plant? When we consider the height of our tallest trees, we realize that it must require an enormous force to bring water to their leaves. We should say at the start that there is still much controversy as to the cause of the rise of sap in plants. We will give briefly what seems to be the most plausible and widely accepted explanation.

Exercise 46. The pull of water in stems due to loss of water from the leaves. Arrange a demonstration of the lifting power of transpiring leaves. Secure a shoot with a long stem, and cut it off to a proper length under water. Fill a tube with water, and insert the twig, previously pushed through a rubber stopper. Make sure that the stopper fits very tightly into the tube, and that the twig fits tightly into the stopper. Sealing wax may be used to insure a water-tight connection. Dip the lower end of the tube into a

dish of mercury. As the shoot loses water, it is withdrawn from the water of the tube, and mercury is drawn upward. Observe and record results.

From this experiment, it will be seen that when the leaves of a plant lose water to the atmosphere, they exert a pull on the water in the conducting system of the plant. It appears that the water column in the plant is continuous and unbroken from the leaves to the roots. The pull exerted in the leaves is transferred all along the conducting system to the roots. If a leaf cell loses water to the atmosphere, the sap in that cell becomes more concentrated; by virtue of the greater concentration of the sap, water passes from adjoining cells, the sap of which in turn becomes more concentrated, and so on to the conducting vessels in the leaves. Hence there is exerted, at the top of the continuous water column, a pull which is transmitted downward throughout the whole plant. It used to be thought that the water in a stem was "pushed" upward by what is called a "root pressure." Although root pressure may play a small part in the rise of sap, there is more substantial proof that the rise is due to a pulling force. **The initial pulling force is created by the loss of water from leaf cells.**

Problem 5. What are the processes of food building?

In the preceding paragraphs we have discussed the movement of the water and mineral salts from the soil to the mesophyll cells of the leaf, and also the movement of carbon dioxide from the atmosphere to these same mesophyll cells. Here, the raw materials used in food-making meet, and here the process of food manufacture goes on.

The rôle of light in food-building. In any manufacturing process, energy is required. In the primary food-making process, light is the energy used; it is absorbed by the green coloring materials. The living substances make use of the energy in building a food from the raw materials, carbon dioxide and water. The manufactured product is a simple sugar. The elements carbon and oxygen, of carbon dioxide, have been united to the elements hydrogen and oxygen, of water, in such a way as to form sugar. Some oxygen is left over from this process, and most of this passes out into the air.

Exercise 47. To find out whether leaves make starch only when exposed to light. It can easily be determined whether light is necessary for the manufacture of carbohydrates in leaves. We have learned that sugar is probably the first carbohydrate manufactured; as a rule, some of it is changed to starch and accumulates during the day in the leaf. The presence of starch may be detected by treating the leaf with iodine, which turns starch grains bluish-purple. A simple experiment consists in covering a portion of a leaf attached to growing plant, which has been in the dark a day, with tinfoil to exclude the light. Then expose the plant to the light for several hours. At the end of that period, remove the leaf from the plant, extract the chlorophyll by warming the leaf in alcohol, and then treat the leaf with iodine. What is the action of the iodine on the portion of the leaf which was uncovered? What does this indicate? What is the effect of the iodine on the part which was covered? Explain.

Exercise 48. The rôle of chlorophyll in food-building. To find out whether it is only in the green parts of leaves that starch is made, extract the clorophyll from a variegated leaf of *Coleus*, or other plant which has white areas in it, which has been exposed to light for several hours, and treat with iodine. Note the effect of the starch on the parts of the leaf which were white and on the portions of the leaf which were green. Write a paragraph explaining the results of this experiment.

The end-products and by-products. In most plants the first visible product of photosynthesis is starch. In many of the *Musaceae* (banana family), starch is absent from the leaves, oil being the first visible product of photosynthesis. In many other monocotyledons there is no visible product of photosynthesis to be found within the green cells, for the sugar produced remains in solution.

The sugar which is the immediate product of photosynthesis is generally assumed to be glucose ($C_6H_{12}O_6$). There is some evidence, however, that it may be sucrose (cane sugar) ($C_{12}H_{22}O_{11}$). Both of these sugars are present in considerable quantities in plants.

The equation which has been used to express in simple form the chemical changes which take place during photosynthesis ($6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$) shows that oxygen is freed during the process. This gas is a by-product of photosynthesis.

Exercise 49. To determine whether oxygen is given off in photosynthesis. In a gallon battery jar place a bunch of fresh, active *Elodea* plants. Keep in sunlight. Over them invert a wide funnel, and over the tube of the funnel

place a test tube filled with water, so arranged as to catch the gas bubbles which are given off. Apply the oxygen test to the gas.

The process summarized. We see that, in the process of carbohydrate manufacture or photosynthesis carried on only by green plants, and only in those tissues of green plants which possess chlorophyll, carbon dioxide and water are the raw materials; sunlight, the energy; special living green bodies chiefly in leaf cells, the factory or laboratory; sugar, the final product; and oxygen, the by-product. Carbohydrate manufacture is a process carried on only in cells containing a green coloring matter and only in the presence of light.

Careful measurements have been made of the amount of light energy which is absorbed by the green leaf, and of the quantity of this actually used in food-making. It has been found that about 10 per cent of the total light energy which falls upon the leaf is absorbed by the green coloring matter, and that of this amount only about 35 per cent is used in food-making. This means that approximately 3.5 per cent of the energy falling on the leaf is utilized in carbohydrate building.

Problem 6. What use does the plant make of the food manufactured in green tissue?

The sugar, **glucose**, which is thought to be the immediate product of the photosynthetic process, is the **foundation material used in the synthesis of most other plant substances.** Part of this simple carbohydrate is respired, liberating energy to be used by the plant in doing work. Some of it is stored as such, to be changed later into various other substances.

Respiration. Respiration is one of the vital processes in plants. In all essential particulars the process is the same in plants as in animals. It is true that plants do not have organs in any way resembling lungs, which serve to facilitate the exchange of gases between the atmosphere and the cells of the body, but the essential features of respiration are the same in both plants and animals.

Respiration is a process which goes on only in the living cells. Every cell of the plant body must respire if it is to maintain its life.

We have often been led to believe that leaves are the respiring organs of the plant. It is true that respiration is quite rapid in leaves, but they are no more the respiring organs of the plant than are the stems, the roots, or other living parts. Moreover, respiration is not going on any more rapidly in leaves than in many other living organs of the plant. It is in all living cells, no matter in what organs or tissues they may be found, that respiration takes place.

Respiration is a process in which substances of the plants, such as sugars, are broken down by the aid of oxygen into simpler products, the principal ones of which are carbon dioxide and water. It is a destructive process. In this breaking-down process, energy is liberated. Some of the energy of respiration is used directly by the living cell for the processes which are essential to its life; the remainder is lost as heat. In respiration, plant foods are used up, being oxidized or "burned" by means of oxygen. In many respects respiration is similar to combustion. As far as each living cell or the entire plant body is concerned, the exchange of gases involves an intake of oxygen and an outgo of carbon dioxide.

There may be some confusion regarding two of the important processes of the green plant, namely, **carbohydrate manufacture (photosynthesis)** and **respiration**. In preceding pages the carbohydrate-manufacturing process of plants was described. This process, too, goes on in the living cells, but only in those cells which are exposed to light and contain a green coloring matter (chlorophyll). And, in the carbohydrate-manufacturing process, carbon dioxide is taken in, and oxygen given off. This is just the reverse of the gas exchange in respiration. Carbohydrate manufacture takes place in a relatively few cells of the plant, and only during the day. Respiration, on the other hand, proceeds day and night in all living cells, whether they contain chlorophyll or not. Again, we should recognize that whereas respiration is a food-destroying or energy-releasing process, that process peculiar to green cells is a food-building or energy-storing process.

It is very probable that there are times during the day when respiration and carbohydrate manufacture go on at about the same rate in the green tissues of the plant. At such times, the oxygen set free in the latter process is not lost to the atmosphere but

is immediately utilized by the cells in respiration, and the carbon dioxide eliminated in respiration is taken by the green cells and used in the process of carbohydrate manufacture. But during the night, when the utilization of carbon dioxide in food-building ceases, this gas escapes from the plant to the atmosphere. In an actively growing green plant, the amount of oxygen liberated to the atmosphere by the carbohydrate-manufacturing process during the twenty-four hours exceeds that absorbed in respiration, and the carbon dioxide contributed to the atmosphere by the respiration of such a plant is much less than tnat absorbed during carbohydrate manufacture. Thus, we see that green plants play a great part in the scheme of nature, in that they maintain a proper ratio of the important gases of the atmosphere, by removing carbon dioxide from it and adding oxygen. It has been computed that approximately 280 square feet of green leaf surface will give out, during a moderately warm and sunny day, the quantity of oxygen used by a man for respiration during the same period.

Materials which compose the plant skeleton. Glucose may be changed into **cellulose**, a carbohydrate which enters into the structure of cell walls. **Cellulose is the most abundant carbohydrate in the plant kingdom.** Cellulose is the basis of a large number of commercial products such as paper, explosives, cellophane, celluloid, rayon, etc. Glucose may be changed into pectic substances. Pectic compounds occur in the cell walls of many fruits, breaking down in boiling to form a jelly.

Reserve foods. Glucose may be changed into other sugars such as **fructose** and **sucrose.** Fructose is common in the fruits of plants. Sucrose is a reserve food, particularly abundant in the root of sugar beet and in the stems of sugar cane.

Glucose, or other carbohydrates, may be converted into fats or oils. Fats and oils are especially abundant in seeds and fruits. Common oils of commerce are castor, linseed, cottonseed, olive, coconut, and peanut. State the commercial uses of these different kinds of plant oils.

The proteins, substances of importance in such seed as beans, peas, and cereals, are also in large part built from carbohydrates, chiefly glucose. In addition to the elements carbon, hydrogen,

and oxygen, which occur in all carbohydrates, proteins also contain **nitrogen**, **sulphur**, and some of them **phosphorus**. These three elements are derived from mineral salts which come from the soil. Frequently we have mentioned the mineral salts as **raw materials** in the food-manufacturing process. They do not form any part of glucose, but they do enter into the make-up of all plant proteins and many other important plant substances.

Various secretions and other substances. But these foods—carbohydrates, fats, and proteins—are not the only plant substances of economic importance. Consider the various plant pigments, the resins and gums, the milky latex of many plants, some of which yield the latex from which rubber is made, and the alkaloids—nitrogenous substances such as quinine (from bark of cinchona), caffeine (from coffee), thein (from tea), morphine (from the poppy), nicotine (from tobacco), and atropin (from nightshade). Also a large number of organic acids are found in plants, such as citric acid (from citrus fruits); there are innumerable essential plant oils, such as lemon oil, cedar oil, clove oil, vanilla, camphor, etc. Also, consider the great commercial importance of tannin, a bitter substance found in the bark of many trees and employed in the tanning of leather.

Thus we see that the sugar, glucose, manufactured only in green cells, forms the foundation of many other plant foods, and other plant substances that probably cannot be classed as foods. Glucose is manufactured in the cells only when they are exposed to light. However, all the other chemical changes in the plant, including the synthesis of fats, of proteins, of alkaloids, of acids, or essential oils, and other substances, are independent of direct sunlight. Sunlight is directly necessary for only one process, namely, photosynthesis, or the building of glucose out of carbon dioxide and water. We have seen that glucose manufacture utilizes the energy absorbed from light. In other words, **in glucose manufacture radiant energy is transformed into the chemical or potential energy of the glucose molecule.** In all other chemical changes in the plant, for example, the synthesis of proteins, the energy for doing the work is derived from respiration.

Problem 7. What is the rôle of the different elements in the nutrition of green plants?

In the preceding sections it was emphasized that only green plants have the power of manufacturing, from the simple compounds derived from the soil and atmosphere, the foods which are used in nourishing the plant body.

We have also seen that this food-manufacturing process is of great significance, in that the foods constructed furnish the material out of which the bodies of both plants and animals are built; and moreover, in the making of these foods by green plants, energy from the sun, which is the world's great and only source of energy, is stored.

It has long been realized by agriculturists that a proper fertilizer practice was dependent upon a knowledge of the influence which the different chemical elements exert upon the plant's growth. If, for example, we would apply nitrates to the soil, we should know how this salt is going to affect the crop. Moreover, we should be able to tell when a crop is suffering from a deficiency of any essential chemical element, and what the effects are of an excess.

Principal substances used by green plants. It was also pointed out that there were certain substances which the plant must have in order to maintain life. The principal substances which are taken into the green plant, and in some way made use of, are as follows:

From the soil. (1) Water, and (2) salts containing principally nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and iron. **From the atmosphere.** (1) Carbon dioxide and (2) oxygen.

Let us briefly discuss the part that each of these substances plays in the life of the plant.

Water. The living material (protoplasm) of the plant is 80 to 90 per cent water. We have learned that **water is an essential raw material for the manufacture of sugar. Water is the solvent of the gases, oxygen and carbon dioxide, and also of all mineral salts.** None of these substances can enter the plant unless they are in solution. We have seen that raw materials and foods move

from one part of the plant to another in watery solution. **The cells of the plant function normally only when distended with water.**

Nitrogen. Nitrogen is a constituent of all proteins, which are essential components of protoplasm. Protein contains 15 to 19 per cent of nitrogen. It is well known that an abundance of nitrogen tends to produce a rank growth of leaves, stems, and roots and to retard the date of maturing of the plant. Crops grown for their leaves only are improved by applications of nitrate. However, an excess of nitrogen in such a crop as cabbage may result in a softness and tenderness which make it difficult to ship and keep well. Cereal crops produce, as a rule, too much straw, and "lodge" badly if there is an excessive supply of nitrogen. An excess of nitrogen applied to potatoes stimulates a leafy growth, but not a proportionate weight of tuber; applied to tomatoes, it produces too much leaf and too little fruit; applied to sugar beets, it results in high tonnage, but reduced sugar content. Heavy applications of nitrogenous fertilizers to fruit-bearing plants may cause increased vegetative growth, which is usually associated with decreased fruit production. **Nitrates are by far the most available source of nitrogen for crop plants.**

Phosphorus. Like nitrogen, phosphorus is a constituent of proteins. It is essential to a rapid multiplication of cells. It is known that such insoluble carbohydrates as starch are not changed into the soluble form (sugar) unless phosphorus is present. In the early stages of the plant's growth, phosphorus promotes development. The fact that applications of phosphorus to the soil hasten the maturity of plants is probably due to the stimulation of rapid early growth. On heavy soils, where roots do not form well, phosphorus stimulates root development. Plants secure their phosphorus from the soil phosphates.

Sulphur. This is an indispensable element in plant growth. It is essential to the formation of proteins. A deficiency of sulphur results in a failure of the cells to divide at a normal rate, and in a suppression of fruit development. The characteristic flavor of onions and garlic is due to certain sulphur compounds. Plants secure sulphur from the sulphates of potassium, calcium, magnesium, and iron.

Potassium. Potassium is essential to the manufacture and movement of carbohydrates. Such plants as sugar beets, potatoes, and others which manufacture and store large quantities of carbohydrates are particularly responsive to the available supply of potassium. This element has a marked effect on the weight of grain. Potash starvation shows in the dull, yellowish color of the foliage, in a loss of vigor, and a lessened resistance to disease.

Calcium. This element seems to stimulate root growth. A deficiency retards the movement of carbohydrates in the plant and their utilization by the plant. Calcium aids in neutralizing acids, both without and within the plant, which might limit the growth. Calcium enters into the composition of the middle membrane of cell walls.

Magnesium. It is now known that magnesium is necessary for the formation of the green coloring matter (chlorophyll) of plants. In fact, it is a component of the green coloring matter. A deficiency of magnesium results in pale, colorless foliage. Magnesium also appears to aid in the movement of phosphorus in the plant.

Iron. Although iron does not enter into the composition of chlorophyll, it is absolutely essential to its formation. Even in the light, plants become pale when grown without iron. Very small amounts of iron salts in the soil are sufficient.

Carbon. As has been stated, green plants derive all their carbon from the air in the form of carbon dioxide. Carbon enters into the composition of all carbohydrates, such as sugars, starches, cell walls, and is also an essential component of fats, of proteins, and of living material itself. Carbon makes up from 40 to 50 per cent of the dry weight of all plants.

Oxygen. This element enters into many chemical compounds, but in its elemental form is essential in the process of respiration. This important process will be discussed later.

It should be understood that the plant is taking in a great many more chemical elements than those mentioned in the preceding paragraphs. The fact is that an analysis of plant ash reveals the presence of most of the elements which occur in the soil. However, it is not known what part, if any, many of the rarer elements play in the plant's life. It may be that some of them, like iron,

even in small traces, are indispensable to normal plant growth, or at least influence the plant's development. Experiments seem to bear out the truth of this statement. It should also be pointed out that the salts of the soil are ordinarily in very dilute solutions, and are taken in by the plant in small quantities.

Problem 8. Where do foods move in the plant?

Although all living cells of the plant contain sap, not all of them are concerned in its rapid movement throughout the plant. In all stems and roots, there is an upward-moving sap stream and a downward-moving sap stream, and these differ in their chemical composition. The **upward-moving stream** is mainly water and mineral salts from the soil, and food substances which have been stored in roots and stems; the **downward-moving stream** carries food substances, dissolved, of course, in water.

We learned that the conductive tissues of the plant are grouped into bundles called vascular bundles. Each bundle is composed of three groups of structural elements, the **xylem**, the **phloem**, and, in most plants, a **cambium** between the xylem and phloem. We learned that water and mineral salts moved in the vessels and tracheids of the xylem. That is, the upward-moving sap stream is in the xylem or woody portion of the stem. Now recall that the conducting elements in the phloem are **sieve tubes.** Girdling experiments with stems show that foods, chiefly sugars, are transported in the sieve tubes of the phloem. That is, the downward-moving sap stream is in the phloem or bark portion of the stem. And bear in mind that all foods which are moving from one part of the plant to another are in solution. Starch grains or protein granules cannot move as such throughout the plant. Why?

In **girdling**, the bark is cut completely around the stem down to the wood. That this operation does not stop the upward flow of water is evidenced by the fact that the leaves do not wilt. But foods do not move past the girdle. This indicates that their conduction is in the bark. If the main trunk of a tree is girdled, the roots are starved for want of food, and the tree finally dies. The girdling of stems often results in increased growth above the girdle. This condition also seems to show that there is a downward move-

ment of foods in the bark, and that they have a tendency to accumulate above the girdle, thus supplying material for additional growth.

The path of movement of the food manufactured in the mesophyll cells of the leaf is probably as follows: It diffuses into cells joining the vein endings in the leaves, from one cell to another, until it comes to sieve tubes; once in the sieve tubes it is free to move rather rapidly to all parts of the plant, passing down into the petiole, thence to the stem and roots.

Problem 9. How does the plant store and digest its food?

As a rule, the food that is manufactured by a plant accumulates faster than it is needed. Accordingly, there is some provision for the storage of food. The amount of food stored and the place of storage depend somewhat upon the length of life of the plant. For example, in **annual** plants, those that live but one year, the supply of stored food is confined to the seeds. In **biennials**, plants that live two years, producing seed at the end of the second year, not only is food stored in seeds, but also large amounts occur in roots. Examples of such plants are carrot, parsnip, turnip, sugar beet, etc. In **perennials**, plants that live from year to year, food is stored not only in seeds, but also in large quantities in roots and stems. For example, the dandelion root is perennial, and at all times has a supply of food in reserve. Well do we know this, for if the dandelion is cut off, new shoots promptly arise, making their growth at the expense of food stored in the roots. Many perennial weeds have underground stems; examples are wild morning-glory or bindweed, Canada thistle, and Russian knapweed; and many common economic plants, such as Solomon's seal, *Trillium*, certain larkspurs, Irish potato, Jerusalem artichoke, asparagus, and others also have underground stems. In all these plants, the underground stems are food-storage organs. In woody plants, the trees and shrubs, food is stored in twigs and branches of all sizes, in the main trunk, and in the roots. In fact, a tree lays up for the dormant season an enormous reserve of food which, in the spring, moves into all the buds, furnishing nourishment for their early growth. In the woody stems and roots, foods may be stored in

the vascular rays, in wood parenchyma, in phloem parenchyma, in cortex, and in pith.

The kinds of stored foods. The principal stored foods are starch, sugars, proteins, and oils. Probably the most common food stored in plants is **starch**, as for example in the seeds of corn, wheat, oats, and rice, the tuber of potato, and in the roots and stems of woody plants. Starch occurs in the form of grains, the shape, markings, and structure of which are characteristic of each species.

Exercise 50. Starch test. Apply the starch test to sections of a number of different kinds of structures including seeds, roots, and stems. Write up your observations.

When photosynthesis is actively going on, starch usually accumulates in the leaf, and can be detected by applying the iodine test described on page 40. This accumulation means that glucose is being made more rapidly than it can be carried away, and that it is changed to starch and stored as such temporarily. That this is so is borne out by the following simple experiment. Small portions of a leaf tested for starch in the evening after a day of photosynthetic activity show starch. If pieces of the leaf are taken in the morning before it is light, or if the leaf is covered with opaque paper in the evening, so that light does not strike it in the morning before the sample for testing is made, a test for starch is negative. Evidently during the night stored food has moved out of the leaf to various parts of the plant. Thus starch may be a temporary storage product of leaves.

Sugars, chiefly glucose, fructose, and sucrose, are very common stored foods. Usually they may be detected in the sap of cells in almost any part of the plant. They are stored in large quantities in certain fruits and in some vegetative structures. Notable examples are the roots of sugar beet and the stems of sugar cane, which may contain from 15 to 20 per cent of sucrose.

Proteins are also an extremely common storage product, especially in seeds, particularly such seeds as beans and peas. Oil is a reserve food in such seeds as flax, cotton, olive, and peanut.

The process of food digestion. Plants digest their foods, and essentially in much the same manner as animals. As an example,

let us consider starch. We have learned that substances which move from place to place in the plant must be in solution. Starch grains can not move through cell walls and protoplasmic membranes. Consequently, starch stored at points in the plant far removed from growing points, where it is most needed, must first be changed into some form which will diffuse through cell walls and protoplasmic membranes. **This change of starch, a substance which is not soluble in the cell sap, to a material which is soluble in the cell sap, is a process called digestion.**

Digestion is brought about by various complex substances known as **enzymes.** They are protein in character. They are usually present in very small amounts in cells, but it appears that even a small quantity may be sufficient to bring about the digestion of a relatively large amount of material. Moreover, there is no appreciable decrease in the amount of enzyme as a result of its action. There is a specific enzyme, known as **diastase**, through the action of which starch is changed to sugar, glucose. Diastase has no other digestive function; its action is specific.

Let us illustrate the processes of digestion, movement of food, and storage of food as they occur in the potato plant. The cells of the potato plant which contain chlorophyll manufacture sugar from carbon dioxide and water. Some of this sugar, as such, is immediately conveyed from the leaf and goes to various parts of the plant where it is used in respiration and to nourish the tissues. Some of it reaches the developing tubers underground. Some of it may form the basis for fats and proteins. And a large proportion of it is converted to starch and temporarily stored in leaf cells. At night, when the sugar-making process has stopped on account of the lack of light, the temporarily stored starch is digested, that is, converted to a soluble form, which in this case is sugar. The agency causing this change is the enzyme **diastase.** The sugar moves out of the leaf, through the leaf stalk into the stem, down through conducting tubes of the vascular bundles, and into the tubers. This sugar is converted back into starch and stored as such in the tuber. The potato tuber is a starch-storing organ. When the tuber is planted and begins to sprout, it becomes sweet, indicating that starch is being converted to sugar. Further-

more, actual test shows sugar on the increase and in transport to the developing sprouts.

As another illustration, let us start with starch stored in the vascular rays of a peach twig. Vascular ray cells are living; in fact, **food storage occurs only in living cells.** When temperature and other conditions are favorable in the spring, these vascular ray cells begin the secretion of diastase, and stored starch is changed to sugar, that is, **starch is digested.** The sugar diffuses from vascular ray cells into adjoining tissues and finally reaches the growing cells in the buds.

There are many different kinds of enzymes, each having a rather specific function. **Lipase** is an enzyme which facilitates the breaking down of fats into glycerin and fatty acids; **pepsin** digests proteins, converting them into water-soluble peptones and proteoses; **trypsin** digests peptones and proteoses, changing them into amino acids.

Enzymes may be secreted by any living cells of the plant, or wherever digestion is necessary.

Exercise 51. Starch digestion. Place some starch in a small, shallow dish and cover with a solution of diastase, which may be obtained as a commercial product. Keep at a temperature of about 75° to 80° F. for 12 to 24 hours. Examine the starch grains with the high power of a compound microscope, and observe that they are " eaten " and corroded. If facilities permit, test some of the solution for sugar.

Problem 10. How does the plant assimilate food?

Up to this point in our discussion of the nutrition of green plants we have discussed the processes of food manufacture, its storage, its digestion, its use, and its movement within the plant. Digested food within the plant cell is not a part of the living protoplasm. One more step is necessary—that of making it a part of the living protoplasm itself. It must be changed from lifeless food to living protoplasm. This process is called **assimilation.** The nature of this transformation is not understood. But we may be assured that everywhere throughout the plant, in living cells, there is going on this marvelous change of non-living foods to living stuff. But the change is brought about only by the action of other living matter already existing.

ADDITIONAL QUESTIONS AND EXERCISES

1. Define organic substances and inorganic substances, and cite examples of each.
2. Which classes of substances nourish the bodies of plants and animals?
3. What is the great rôle that green plants play in the world's economy?
4. What inorganic compounds do living plants give off?
5. What elements do carbohydrates contain?
6. Why is a sprouted potato sweeter than an unsprouted one?
7. Sweet-corn kernels contain much more sugar than field-corn kernels. Do you see any relation between this fact and the wrinkledness of dry sweet corn?
8. What is meant by an independent plant?
9. Define assimilation.
10. Discuss digestion in relation to seed germination.
11. When slices of red beet are placed in water what prevents the coloring matter from diffusing out? Why does the coloring material come out when the beet is boiled?
12. What is the difference between the food of plants and that of animals?
13. What gases enter a green leaf in sunlight?
14. What is an enzyme?
15. Explain why an apple tree dies eventually when a ring of bark is removed from the main stem.
16. Explain why a tree girdled in summer may live and remain green during the remainder of the season but fail to leaf out the following spring.

REFERENCE

The Green Leaf, by D. T. MacDougal, published by D. Appleton and Company, 1930, 142 pages, 22 figures. Mention of chapter headings shows how much there is of interest in this little volume: living matter from rocks, water and air; place in the sun; models of sun-screens and our utilization of their products; the grass blade; pine needles; tree records of climate; the oak leaf; movements of sap and autumnal colors; green stems; a visit to green leaf mills; green mills and their grist; protoplasm, how it started and how it goes; growth; ghost and other dwellers in darkness; leaf-products and human populations.

UNIT III

NUTRITION OF NON-GREEN PLANTS

We learned in Unit II that green plants make their own food. For this reason they are called **independent plants,** or **autophytes.** Plants without chlorophyll and the animal life of the earth are **dependent,** since they have not the power to make food, but must get their food from supplies furnished, directly or indirectly, by green plants.

Almost all the non-green plants are included in the groups which we know as bacteria, yeasts, molds, mildews, rusts, smuts, and mushrooms. Certain of these plants are related in an important way to man's welfare. They get into his foods which are unprotected and cause them to spoil. They enter his body and the bodies of animals and produce poisonous substances that cause disease. In a similar way they affect plants, causing serious damage to cereals, fruits, and other crops. Through unceasing effort scientists have learned much about the nature of these plants and about how they live, and this knowledge has been a help to mankind in protecting against the injurious forms.

Although certain of the bacteria, yeasts, and molds are man's enemies, we should know, also, that representatives of these plant groups are absolutely essential to the existence of other life on the earth. Without the help of the microscopic forms of life which are working quietly within the soil, the continued existence of man and his civilization would be impossible. Certain of the soil bacteria and molds cause the decay of dead plant and animal bodies. Others use the nitrogen of the air in making new chemical compounds which are essential to the growth of other plants. In this way the soil is kept fertile, making possible the production of plants year after year.

In general, the non-green plants are simple forms without roots, stems, or leaves; yet there are a few flowering plants which

lack chlorophyll and so must depend upon green plants. Among the dependent seed plants are the Indian pipe and pinesap, which derive food from dead plant materials in the soil, and beech drops and squaw root which live as parasites on the roots of certain trees.

It will be interesting to study the relationships between the independent life of the earth and the dependent life. Green plants, in the process of food-making, use carbon dioxide in large amounts and give off to the atmosphere an equal volume of oxygen; in respiration, they use oxygen and give off carbon dioxide in small quantities. The ultimate effect of green plants on the air is to decrease the amount of carbon dioxide and increase the amount of oxygen. Animals and non-green plants affect the atmosphere by increasing the amount of carbon dioxide and decreasing the amount of oxygen through the process of respiration. Thus there is a balance in nature between green plants and living things without chlorophyll. The plants with chlorophyll furnish oxygen which all living things require and use carbon dioxide which is a waste product of all life.

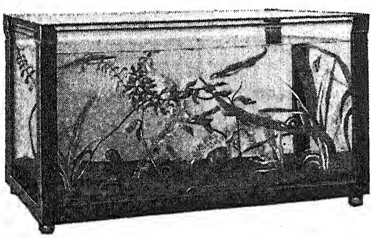

FIG. 32.—A balanced aquarium. Denoyer Geppert Co.

A balanced aquarium (Fig. 32) is set up by adding animals and plants to the water in proportion so that the plants will furnish the animals the required amounts of food and oxygen and the animals will furnish supplies of carbon dioxide and other raw materials needed by the plants. The balanced aquarium is a miniature world with a definite balance between the plant life and the animal life which it contains.

We can consider green plants independent only in the sense that they are able to build foods from raw materials; they are dependent, in a way, since a large part of the raw materials necessary for the process of food-making is furnished by other forms of life.

Problem 1. What are the main characteristics of the non-green plants?

The outstanding characteristic of the non-green plants is the absence of chlorophyll in their tissues. In a field planted to corn an occasional plant appears with white leaves. No one has seen a full-grown stalk of corn having only white leaves. It is significant that these young albino corn plants live only as long as the food stored in the seed lasts. The parent plant had chlorophyll, so food could be produced and stored in the seed. The albino seedling, having no chlorophyll, must die as soon as it has used this original store.

There are no chlorophyll-bearing forms among that simple group of plants known as fungi. The plant begins development in contact with organic material, and all its needs for producing the plant body and reproductive structures are supplied in the form of ready-made food.

All living organisms need energy for life processes. Whether plant or animal, every living thing uses oxygen and gives off carbon dioxide. Substances are oxidized in the cells of the living body, and energy is released. If the living thing can not store energy for itself in the form of food it must get its supply of energy from the store provided by other living things which can make food.

We have considered non-green plants dependent on green plants, but certain bacteria are exceptions. Anyone who has seen a mineral spring has noted the foul smell and the whitish or yellowish coating of objects in the stream of water running away from the spring. The same may be noted in a sluggish stream containing sewage. The smell is due to a gas known as hydrogen sulphide which escapes from solution in the water. The coating of objects is due to sulphur bacteria. These bacteria are primitive forms which can live and secure energy from the oxidation of hydrogen sulphide to sulphur and the oxidation of sulphur to sulphuric acid. These or similar forms must have represented the first life on the earth when very few of the types of animals or plants found today could have survived the severe conditions.

Saprophytes. Dependent plants which derive their food from **non-living** organic material are known as saprophytes. The

organic matter may be either plant or animal. There are a great many different kinds of saprophytic fungi. Mushrooms are a common example. They may be grown in beds prepared from partially decayed stable manure mixed with rich loam. The decayed manure and loam furnish the organic material for the use of the mushroom. Enzymes are secreted by the part of the plant consisting of a network of tiny underground threads. These enzymes change the complex food substances into simpler materials which can pass through the membranes of the plant in absorption. Inside the plant the food materials may be oxidized, or they may be assimilated, forming protoplasm which is used in the building of new plant structures. A saprophyte is similar to an animal in that it requires food which has been derived directly or indirectly from a green plant.

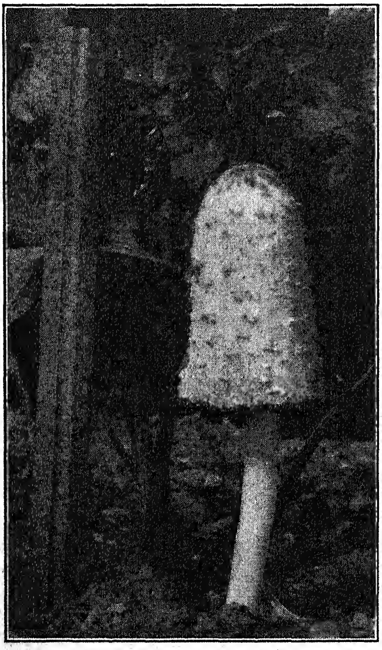

FIG. 33.—Shaggy-mane mushroom growing in a city backyard. Why is this mushroom growing here among the green plants? Does it need the sunlight? Are the materials which it takes from the soil the same as those taken by the green plants? Could plants without chlorophyll develop without the aid of green plants? Could green plants succeed without the aid of the non-green plants?

Why are mushrooms frequently found growing in the woods around dead trees or stumps? Explain why mushrooms are found growing in soils that have humus (decaying plant material).

During the hundreds of thousands of years that life has been in existence on the earth enormous quantities of material have been produced in the form of animal and plant bodies. It is to be noted that these materials have not accumulated on the

surface of the earth. Without the great variety of saprophytes which dispose of the dead organic substances, life on the earth would have become impossible long ago because of the débris resulting from the accumulation of these materials.

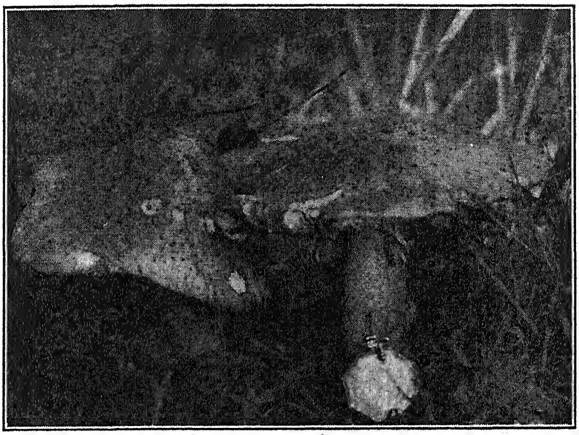

FIG. 34.—These large mushrooms are saprophytes, getting food materials from the humus on which they are growing.

The annual herbaceous plants and the leaves of trees and shrubs fall to the ground each year, and myriads of non-green plants begin the process of transformation. The complex plant materials are attacked in the process of decay, and this and other processes which follow change these substances into simple raw materials suitable for use of other plants. In the same way, the parts of crop plants which are not removed from the fields by man are returned to the soil where bacteria and molds transform them into materials that can be used by other crops. What conditions would follow if all the saprophytes were suddenly destroyed?

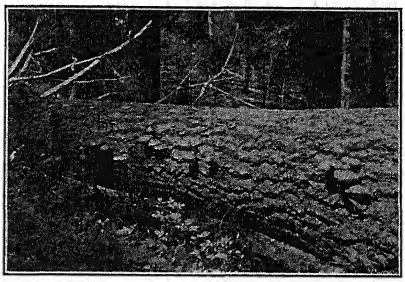

FIG. 35.—Certain fleshy fungi live as saprophytes on fallen logs and on stumps.

Saprophytes are not always beneficial to man. Good food for man is also suitable food for other organisms which may get in and spoil the food for man. It has been necessary for man to devise methods of food preservation such as drying, canning, use of chemicals, and refrigeration in order to make it impossible for injurious saprophytes to enter or grow in the food and thus destroy it.

Exercise 52. How does a saprophyte secure food? Mount in water on a clean slide a small portion of rotten apple or orange, cover with cover-glass, and examine under the low power of the microscope. What evidence do you see of plant growth within the apple? What is the source of food of the structures which you see? How does the food material of the apple get into the plant body of the fungus?

Exercise 53. How may saprophytes be spread? Examine an apple or orange in the advanced stages of rot for any evidence of the fungus on the outside of the fruit. Mount on a slide in water under a cover-glass a small amount of any blue or green powdery fungus material that you may find. What is the shape of the bodies as they appear under the microscope? What seems to be the relation between the structures of the plant which you find on the surfaces of the fruit to those which you found within? Why are the thread-like structures produced within the fruit rather than on its surface? Why were the resistant spherical structures produced on the surface of the fruit rather than within? Show how the part of the plant within the fruit and the part of the plant on the outside is in each case fitted to live where it is produced. How could the small spherical bodies on the outside known as **spores** be spread to other fruits?

Exercise 54. How may saprophytes enter food materials? Place in a dish a sound apple in contact with the rotting portion of an affected apple. On the opposite side of the sound apple prick the skin with the point of a knife and introduce some of the spore material found on the surface of decayed fruit. Cover the dish and examine each day for a few days. Describe fully what happens to both sides of the apple which was formerly sound. What rules would you give for preventing decay in sound fruits, such as apples and oranges?

Parasites. Many of the non-green plants, though dependent like the saprophytes, derive their food from living organic matter, that is, from the bodies of living plants or animals. These are **parasites.** Some of the greatest discoveries of medical science are concerned with methods of protecting against disease-producing bacteria which are parasitic plants. Many cultivated plants and domestic animals are attacked by plant parasites, and huge sums

of money are expended annually by public agencies and private individuals in fighting these parasitic plant pests.

The main point of difference between the saprophytes and parasites is the fact that the parasites derive their food from living plant and animal bodies whereas the saprophytes thrive on dead organic materials. They are alike in the fact that both require organic material for their nutrition, that is, neither has the power to make foods from raw materials.

Since bacteria and other fungi use the living material of plants and animals as food, they naturally are injurious in their relation to the host (the living thing in which they grow). They do injury by destroying the living material of the host. Also, many of them are injurious because they produce substances which are poisonous to the host. These substances are known as **toxins.** Both plants and animals are affected by toxins, but since the animal has a circulatory system and a plant has nothing to compare with this, the toxic substances can not affect the plant in the same way they affect animals.

Many of the most serious diseases which attack man, such as typhoid fever and diphtheria, are due to the effects of bacteria. The non-green plants which produce disease conditions in plants or animals are called **pathogenic forms.** The science which deals with plant diseases is **plant pathology.**

Following the work of Louis Pasteur, a Frenchman, and Robert Koch, a German, showing that bacteria are the cause of many diseases in animals, science has built up a system of preventive medicine. It has been found possible in many cases to prevent invasion of the body by bacteria, and in others, to prevent the most injurious effects of those that have made a start. The medical doctor has come more and more to be an educator, showing people how to keep well.

Suggested activites. You will find interesting accounts of the life and work of Robert Koch and of Louis Pasteur in *Science in the Service of Health,* by Downing (Longmans). Prepare a report to be read to the class on the life and work of Robert Koch. Prepare a paper on the service to mankind of the work of Louis Pasteur.

Problem 2. What are the nutritive relations of the saprophytes?

The principal saprophytic plants of economic importance are the bacteria, yeasts, and molds. All these groups are widely distributed on the earth. Organic materials either of plant or animal origin when exposed under suitable conditions of moisture and temperature are soon alive with representatives of one or more of these forms. The material in which they grow becomes changed. Through the life processes of saprophytes, sweet milk becomes sour, alcohol is formed in fruit juices, and the alcohol solution may be changed to vinegar.

Exercise 55. How are organic materials changed by saprophytes? Place in a fruit jar various dampened plant materials such as pieces of banana, apple, and bread; and other organic materials as cheese and leather. Put on the cover without the rubber, and leave in a dark place at living-room temperature. Examine each day and note changes in the appearance of the materials. Describe and account for the changes from day to day. Why is apple or cheese a suitable material for the growth of saprophytes? Why is it possible for these plants to grow in the dark? Why are they classed as saprophytes? Under what conditions are these forms beneficial? Under what conditions are they injurious to man? Explain the part (if any) that each of the following processes has played in the life of these saprophytes: photosynthesis, diffusion, osmosis, respiration.

The use of saprophytes in the preparation of food. The yeast plant is a very small single-celled plant which reproduces by sending out buds which gradually are pinched off and become new yeast plants. Yeast cells grow in a sugar solution, giving off carbon dioxide gas and producing alcohol. This property of yeast cells is taken advantage of in bread-making. Dough containing yeast plants is kept at a temperature suitable for their growth. As the yeast cells grow, bubbles of carbon dioxide are formed throughout the dough. The bubbles cause the dough to rise. When this is baked, the alcohol escapes and the bubbles remain as holes in the bread, making it light. What is the source of the gas that forms the bubbles in bread dough?

Bacteria and molds are used in the manufacture of dairy products. Butter may be made either from cream as it is separated from the milk or from cream that has been allowed to sour. Sweet cream gives butter which lacks the desired butter flavor and the

butter soon becomes rancid. Sour-cream butter is the common type. The cream is allowed to sour from the action of lactic-acid bacteria. Country butter was formerly made from cream which soured naturally. Now most of the butter is produced in creameries where the cream is pasteurized to destroy wild bacteria present and then pure cultures of the lactic-acid bacteria are added. Under these conditions the flavor of the butter can be controlled.

In the ripening of cheese, the desired flavor is produced by bacteria and molds, the particular flavor depending upon the type of organism present.

Bacteria are also involved in the production of vinegar and in the making of sauerkraut. In a similar way the farmer uses a silo to preserve, by means of the acid formed, large quantities of food (silage) to be fed to cattle in the winter.

Exercise 56. How can we test for the presence of carbon dioxide? Fit into a bottle a two-hole rubber stopper with funnel tube and with delivery tube extending into a test tube of lime water. Dissolve a little cream of tartar in water and pour the solution into the bottle through the funnel tube. Add a solution of baking soda. Carbon dioxide is released from the baking soda by action of the cream of tartar. It changes the appearance of the lime water from clear to milky as the gas bubbles through it. This is a test for carbon dioxide.

Exercise 57. What is the effect of yeasts on a sugar solution? Using the apparatus of Exercise 56, put a solution of one part molasses in nine parts of water into the bottle. Pulverize a small portion of a dry yeast cake and add to the molasses solution in the bottle. Let stand in a warm place for twenty-four hours with the delivery tube extending into the tube of lime water. Is there any evidence of the evolution of a gas in the bottle? Is the gas carbon dioxide? Note the odor of the solution in the bottle. The yeast cells produce an enzyme known as zymase. Sugar is taken into the yeast cell where the zymase causes a decomposition of the sugar with the production of alcohol and carbon dioxide.

Suggested activity. How is yeast used in bread-making? Find out at home or from a baker how yeast is used in bread-making. What are some of the conditions necessary for success in making bread with yeast?

Exercise 58. What is the nature of yeast cells? Place a drop of the liquid from the bottle used in Exercise 57 on a slide. Place over it a cover-glass, and examine under the low power of the microscope. The numerous small bodies are yeast cells. Using the high power, note the shape and structure. The knobs on some of the cells are buds which develop and finally separate, producing new cells. This process, which is the ordinary method of reproduction of yeast, is known as budding.

Food in which saprophytic organisms are growing may or may not be poisonous, but the presence of molds on preserved food is always a danger sign indicating that injurious organisms may be present.

There are two types of poisoning which may result from eating contaminated foods: (1) **the so-called ptomaine poisoning,** and (2) **botulinus poisoning.** In the decomposition by bacteria of fish, meats, etc., which are mainly protein, poisonous substances are often formed which are very toxic when taken into the human digestive tract. These, together with the living bacteria present, may cause serious illness. In the second type of poisoning, an organism which is hard to kill because it forms spores may be sealed up in a can with food, and if the can is not sterilized by heat the bacteria may grow and reproduce in the food. This organism grows readily in the absence of air, and it produces a substance which is very poisonous but is easily destroyed by heating. Between the years 1919 to 1924 there was an outbreak of food poisoning in various parts of the United States. Canned ripe olives caused most of the trouble. As ripe olives are eaten without being cooked, the toxin was taken into the digestive tract. It is well to remember that clean, fresh, sound food will not cause botulism, and preserved foods freshly heated to the boiling point will not cause botulism. Ordinarily there is no danger in eating factory-canned foods as they are subjected in the can to high temperatures sufficient to kill spores as well as all vegetative bacteria.

Food showing any signs of decomposition evident by appearance, odor, or formation of gas should be destroyed. It is unsafe to taste food which shows any of these signs of spoilage.

How may disease be spread by milk? Milk, a balanced food for man, is also a suitable food for bacteria. The souring of milk is one of the first evidences that bacteria are growing in it. Disease bacteria from the cow herself or from infected persons may be present as well as the lactic-acid organism which causes the souring. Diseases which may be spread by milk are tuberculosis (to which the cow is subject as well as human beings) and diseases of human origin as typhoid fever, scarlet fever, septic sore throat, and dysentery. In what ways may harmful bacteria get into milk?

Boards of health of our larger cities set standards for sanitary

production of the supplies of milk which go into the cities. They also maintain an inspection service to see that the standards are met by the dairymen. One of the first requirements is healthy cows. They must pass the tuberculin test—a test to determine the absence of any tuberculosis infection. Stables must be well lighted and kept clean.

Pasteurization of milk. Heat not only reduces the bacterial content, but it may also cause changes in the protein food substances in the milk. Pasteurization is a process in which the milk is kept at a temperature of 65° C. for 20 minutes. This heat is sufficient to kill 95 to 99 per cent of the micro-organisms, and the changes in the proteins caused by heat are reduced to a minimum. Give two reasons why city milk supplies should be pasteurized.

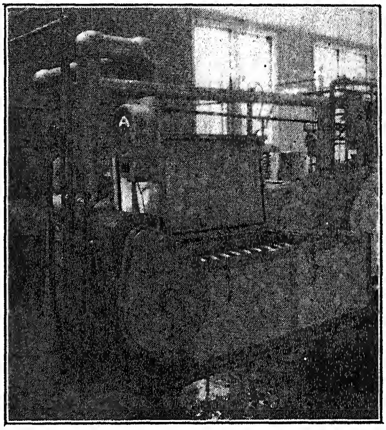

FIG. 36.—A milk pasteurizer. The steam and refrigerator pipes with which it is connected are shown. (From California Agricultural Experiment Station Circular 319.)

Certified milk is produced under the strictest requirements for cleanliness and is thus kept relatively free from bacteria. The cows are kept clean; they are washed before being milked; the milker must wash his hands before milking each cow, and the milk must be cooled quickly. It is not heated but is sold as raw milk. It costs money to observe all the extra precautions required so that when ordinary pasteurized milk may sell for ten cents a quart, certified milk may sell for twenty cents a quart.

The preservation of foods. During certain seasons of the year foods are plentiful in the fresh state. With our modern methods of packing and transportation we really have a wide choice of fresh fruits and vegetables the year round. However, during the winter, certain fresh foods are high priced and man has learned how to preserve foods when they are plentiful so that

an abundance of a wide variety of foods is available throughout the year at moderate prices.

The bacteria, yeasts, and molds thrive on our foods; they can be considered our rivals as they will surely spoil foods for our use if they can get to them first. The methods of preservation sometimes change the flavor of foods, but we have learned to enjoy them and usually the nutritive value is not impaired.

Methods of coping with the saprophytic menace to our food supply are concerned with keeping the micro-organisms out of the food by setting up conditions which make it impossible for them to grow in the food materials.

One of the oldest and simplest of the methods of food preservation is **drying**. Bacteria, yeasts, and molds require water for growth, and it is impossible for them even to begin growth in dried meats, fruits, and vegetables so long as they are kept dry. Drying reduces the amount of water in the food substances; if bacteria or other saprophytes come in contact with them they can not live, since the water molecules are in greater concentration in the cells of the plant than in the food, and water passes from the plant cell and causes its death.

The use of salt and sugar in the preservation of foods is a drying process, and the destruction of bacteria and other plants in this type of food preservation is really the result of osmosis. Water passes from the cells of the invading organism into the food, and the plants are killed by the loss of water.

Sometimes chemicals, such as benzoate of soda and salycilic acid, are used in food preservation, but these are considered injurious to man to a greater or less degree. Meat and fish hung near a smoldering wood fire absorb certain acids from the smoke which preserve the foods without being markedly injurious. Smoking has long been used as a method of preservation of meat and fish.

Methods of food preservation by canning were introduced early in the nineteenth century. These have proved far superior to the older methods. Bacteria do not thrive in the acid juices of fruits. Boiling the fruit for a few minutes kills the yeasts and molds, and if the heated materials are sealed in the can while they are hot, they will usually keep indefinitely in perfect condition.

This type of canning is easily done at home. For peas, beans, corn, and meats, the problem becomes more complex, as the spores of bacteria which may be present in these non-acid substances are not killed by simple boiling and, sealed in the can, the spores germinate and the bacteria reproduce rapidly in the abundant food supply with the result that the food is spoiled for human use. The commercial method of canning these substances consists in placing the hot materials in cans, sealing, and heating them under steam pressure to a temperature of 240° F. for 40 to 60 minutes. This treatment kills the very resistant spores of bacteria on the food and the food can not spoil.

In home canning the cold-pack method is usually followed. The cans of food are sterilized either by steaming in an ordinary steam cooker for 3 hours or by heating in a pressure cooker under a pressure of 5 to 10 pounds of steam for one hour.

One of the commonest methods of keeping the food from spoiling is by keeping it cold. Although the growth of molds and bacteria is not entirely stopped by low temperatures, foods can be kept very much longer if they are kept cold. Ordinary low temperatures used in refrigeration can not be depended upon to prevent food spoilage indefinitely. Mechanical refrigeration has added much to the convenience and safety of preserving foods temporarily by keeping them cold. Foods, especially fish and meats, should be used promptly after removal from cold storage.

Exercise 59. Putrefaction of food materials. Place in a series of test tubes with a little water small bits of food substances, as meat, potato, bread, sugar, starch, flour, beans, and corn meal. Plug with a cotton stopper and leave in a warm place for a few days. What evidence is there that putrefaction has taken place? Is the result the same in all the tubes? What foods, if any, have not putrefied?

Exercise 60. Will dry foods putrefy? Place in a series of test tubes dry food substances as beans, flour, corn meal, rolled oats, dried beef. Plug with a cotton stopper and examine after they have remained in a warm place for several days. Determine whether there has been any putrefaction. What is the relation of moisture to putrefaction?

Exercise 61. What is the effect of heat on putrefaction? Put bits of meat, boiled beans, bread, milk, etc., into a series of test tubes with a little water. Plug with cotton stoppers and heat in a pressure cooker at 10 pounds pressure for 15 minutes, or in steam in a closed vessel for one hour. Set the tubes aside in a warm place and examine after a week. Answer the question of the exercise.

Saprophytes in the soil. Under suitable conditions of moisture and temperature, a fertile soil will continue to support a vigorous growth of plant life year after year, and this has been continuing for hundreds of years. Even large trees have reached maturity and fallen, the wood gradually decomposing and dropping to pieces to become a part of the soil. Leaves, as they fall from the trees each autumn, do not continue to accumulate but gradually disappear, their partly decomposed structures forming humus in the upper layers of soil. We might expect that, while the plants are taking raw materials from the soil season after season, as time goes on it would gradually become exhausted so that it would be less able to support plant growth. This, however, is not the case. In fact, the opposite is true; the soil actually increases in fertility.

Bacteria and molds cause decay. The succession of plant growth on soil is made possible by the action of microscopic plant life. Many different micro-organisms in the soil bring about the decay of plant and animal materials.

Some forms of saprophytes destroy the cellulose which makes up the walls of the plant cell. These are among the most important destroyers of plant material. It is interesting to note that bacteria of this class are present in the intestinal tract of herbivorous animals, such as cattle and sheep, and make digestion of coarse hay and fodder possible. What different things must happen to a piece of wood before the substances of which it is composed can be used by other plants?

The cycle of nitrogen in nature (Fig. 37). One of the most important of the elements used by plants is nitrogen. All protein substances contain this element along with carbon, hydrogen, oxygen, and small amounts of other elements. Although nitrogen makes up four-fifths of the atmosphere by volume, its compounds are the most expensive of the commercial fertilizers. Green plants can not make **direct** use of any of this necessary element in the form in which it occurs in the air. Nitrogen is set free and lost to plants in decaying protein materials, and large quantities of its compounds are lost as sewage. It was formerly thought that when the nitrate beds of Chile became exhausted there would be famine on the earth for the want of raw materials containing nitrogen for plant growth. It has been found that certain micro-

organisms in the soil have the power to bring about a combination of nitrogen of the air with elements in the soil, forming compounds

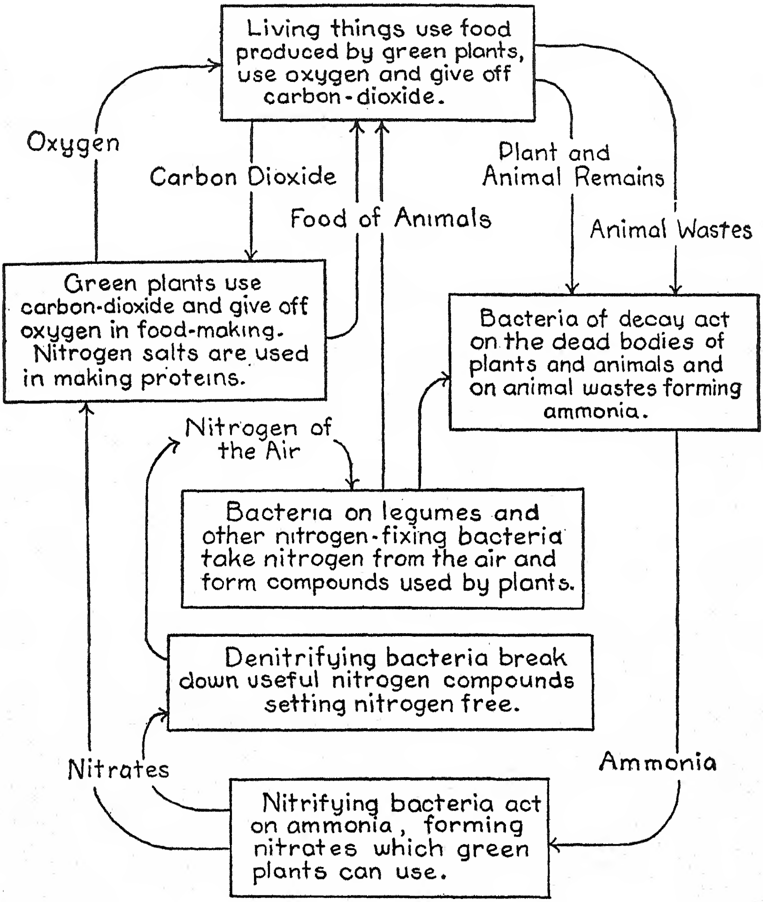

FIG. 37.—Diagram showing the relation of living things in nature. In what ways do other living things depend on green plants? How are green plants dependent on bacteria? What part do the nitrogen-fixing bacteria play in nature? Trace the cycle of carbon in the diagram. Trace the cycle of oxygen as it appears in the diagram. Trace the cycle of nitrogen from the time it is a part of the food of animals, through the different processes until it is again a part of the food of animals.

which plants can use. In this way the supply of nitrogen in the soil may be kept practically constant.

There are two principal groups of nitrogen-fixing bacteria: (1) those which live free in the soil, and (2) those which are associated with the roots of legumes, as red clover and alfalfa. The latter are examples of **symbionts.** At the site of their invasion of the root tissues, galls or tubercles form. The legume absorbs the raw materials, salts and water from the soil, and the bacteria make use of certain of these materials. The bacteria combine nitrogen of the air with materials furnished by the legume to form proteins for themselves; and the legume also makes direct or indirect use of these. In this relationship the two organisms living together are **mutually beneficial.** So dependent are the legumes on the tubercle bacilli that, if the necessary bacteria are not present in the soil, the seed of alfalfa or the soil in which the seed is planted must be inoculated; that is, the necessary form of bacteria must be introduced before the alfalfa can be grown successfully.

It has long been known that **the same crop can not be grown indefinitely year after year on the same soil.** The farmer may grow corn followed by wheat, and with the wheat he may sow clover. The clover crop may be used for hay, but roots and portions of the stem rich in nitrogen compounds are left in the soil. When these materials decay, nitrogen is added to the soil. The system in which different crops are grown successively is known as crop rotation, and every well-planned crop rotation scheme should include a legume every two or three years. Give two reasons why a certain crop should not be grown on the same soil year after year.

The nitrogen-fixing bacteria require well-drained soil which contains organic matter. If it is highly acid, lime must be added to reduce the acidity as these bacteria do not grow well in an acid medium.

In our account of the **nitrogen cycle** we may start with the complex plant and animal proteins. These are broken down by many different soil organisms into simpler and simpler substances until the final products can be absorbed by green plants as raw materials out of which more proteins are made.

The bacteria of decay cause the decomposition of complex proteins in plant and animal remains and the formation of ammo-

nia. Resulting ammonia compounds are changed by other bacteria into nitrites. Nitrities are changed by still other forms into nitrates. Nitrates in solution may be absorbed by the green plant, where they unite with carbohydrates to form amino acids. Amino acids are combined by plants to form plant proteins. Plant proteins are eaten by animals, and animal proteins are formed. The dead bodies of animals and plants are attacked by bacteria, and a new cycle is begun.

It should be noted that not all the bacteria involved in the processes of the nitrogen cycle are saprophytes. The ammonia-formers derive energy from the decomposition of dead plant and animal materials; thus, they are true saprophytes. The nitrate- and nitrite-formers are as truly independent as green plants since their sources of energy are chemical substances, the ammonium compounds. The nitrogen-fixing forms which live free in the soil require carbohydrate foods produced by green plants for their source of energy, and therefore they are saprophytes. The nitrogen-fixing forms which live in tubercles on legume roots derive their energy from the carbohydrates and other food supplies of the cells of the living host plants, and hence they are parasites.

Exercise 62. Root tubercles. Examine roots of a clover plant for evidences of the presence of bacteria. Crush one of the tubercles, and note the milky contents; this material contains the nitrogen-fixing bacteria. Where do they get their food? What do they do for the plant? What does the legume plant do for them? Are they saprophytes or parasites? Show that the legume plant and its nitrogen-fixing bacteria are symbionts. Of what importance are these forms in nature? Of what importance are they in agriculture? In what way does a clover crop add to soil fertility? Write a paragraph showing what would be the result if all the nitrogen-fixing bacteria should cease to function.

Problem 3. How do parasitic plants cause disease in animals?

Comparatively few of the very large number of different kinds of fungi that have been identified have been found to cause disease in animals. Although a number of molds cause disease, such as ring-worm and athlete's foot, yet most of the pathogenic fungi are bacteria.

Leeuwenhoek first discovered bacteria late in the seventeenth century. It was not until two hundred years later that they were shown to be the cause of disease. In a series of epoch-making experiments and in the face of much opposition, Robert Koch, around 1876, showed that anthrax in sheep is caused by a rod-shaped bacterium. He later showed that tuberculosis is caused by another rod-shaped form. Louis Pasteur entered into the study of anthrax in France with a view to finding some method of preventing or curing the disease. His work resulted in a method of preventing anthrax in animals by vaccination. This early work was important as it not only met the immediate need of a method of preventing anthrax but it also laid the foundation for the development of our later knowledge along the lines of disease prevention.

Many pathogenic bacteria produce poisons in the body of the animal which is their host. These poisons, known as **toxins**, cause the symptoms of the disease. It has been found that substances which counteract the toxins are developed in the body of the infected animal. These are known as **antitoxins**.

The resistance of a body to disease bacteria is known as **immunity**. For some unknown reason, some individuals have a **natural immunity** to a certain disease. They do not easily contract the disease. A person who has had diphtheria is not likely to have the disease a second time. He is protected by substances in the blood which are formed as a reaction to the effects of the toxins. This immunity is known as **acquired immunity**. Investigators have learned that diphtheria antitoxins, developed in the blood of a horse, can be used safely in protecting children against diphtheria by providing an immunity. **Vaccination** is practiced by physicians to protect against certain diseases by causing the patient to have a mild form of the disease, with development of an immunity which protects against the more serious form of the disease.

The first successful vaccination was performed by Louis Pasteur in the prevention of fowl cholera in chickens. He later successfully vaccinated sheep against anthrax. **Pasteur's name has gone down in history as one of the greatest benefactors of the race.** He was able to show from his knowledge gained in the

study of dangerous bacteria how bacteria could be kept out of wounds. Keeping a wound free from bacteria is known as **asepsis** (without disease). Lister had already shown how bacteria could be destroyed by the use of chemicals. The term applied to this method of preventing infection is **antisepsis** (against disease). Name five diseases of man which are caused by bacteria.

Problem 4. How may bacteria and molds be studied in the laboratory?

In growing bacteria and molds for study, it is necessary to furnish food materials for the plants and keep the temperature and moisture conditions suitable. It is also necessary to be certain in most experiments that the food materials and glassware used are free from bacteria and mold life at the beginning of the experiment and that they be kept so throughout its progress. Glass bottles or test tubes with stoppers made of wads of cotton can be sterilized by heating in an oven until the cotton is slightly browned. Culture media containing the food for the plants can be sterilized by heating the cotton-stoppered bottles or flasks of the material in a pressure cooker with steam at a pressure of 15 pounds. An ordinary kitchen steam cooker may be used if a pressure cooker is not available. Heating in steam in such a vessel for 30 minutes may not destroy all the spores that may be in the culture material, but this method is sufficiently efficient for use in experiments in high-school classes. Conn's *Bacteria, Yeasts, and Molds in the Home* gives detailed directions for the preparation of media and the doing of many interesting and instructive experiments suitable for the work of high-school classes.

Exercise 63. Bacteria in water. Crowd leaves and stems of water plants into a jar of water and set aside to let the materials decay. Note changes in the appearance of the liquid as decomposition proceeds. Mount on a glass slide under a cover-glass some of the cloudy liquid as it develops. Examine under the high power of the microscope with most of the light shut off. What evidence of life do you see? Does decay give rise to the bacteria, or do the bacteria cause the process of decay? What happens to the solid materials as decay goes on? What is in the water that was not there before decay started? Why is pure water less likely to have living bacteria in it than water polluted with sewage? Why is water from a deep well less likely to contain large numbers of bacteria than water from a river?

Suggested activity. Make a study of the water supply of your community: is it surface water, as that from a stream, pond, or lake; or is it ground water, as that from a deep or a shallow well? Is it likely to have sewage in it and thus carry dangerous as well as other forms of bacteria? Present a report of your study to the class.

Write a report on methods used in your community to make the water supply safe for drinking purposes.

Exercise 64. Bacteria in milk. Put in each of six large-mouth, half-pint bottles one-third of a pint of raw milk that has not been heated. Close each bottle with a wad of cotton. Heat three of the bottles in a steam cooker or other closed vessel with water for half an hour. Label the bottles to identify them, and set aside with the unheated bottles in a moderately warm place. Note the appearance of each of the bottles daily for a week. At the end of that time remove the stoppers and note the odor of the milk in each bottle. Account for any differences. Why is milk a good medium for bacteria? Under what conditions will milk sour? What is the danger in washing bottles, cans, and other utensils used in handling milk in water contaminated by sewage wastes? What is the danger in allowing a person harboring disease germs, as a carrier or himself having the disease, to handle the milk?

Suggested activities. Write an account of the methods used to keep your milk supply free from dangerous bacteria.

Justify the expense of city milk inspection.

Bacteria in the air. Wherever there is dust in the air there are bacteria. Bacteria ride on particles of solid material of which dust is composed. It is true, not every speck of dust has its passenger; but wherever there is dust you can be certain there are bacteria. Most of them are harmless; others are helpful, falling upon organic waste materials and causing them to decay; still others get into exposed foods and cause them to spoil, and we breathe some into our throat and lungs which may cause inflammation. On a mountain top there are few bacteria, but in crowded centers of population they are everywhere in great numbers.

Exercise 65. Bacteria in the air. Wash and dry thoroughly petri dishes with covers. Place them in an oven and gradually raise the temperature to moderate heat. Turn off the heat after half an hour, and when they are cool wrap each dish without removing the cover in paper for protection from dust. Prepare nutrient Bacto agar as directed, and while it is still hot remove carefully the cover of a dish and pour into it enough of the liquid to cover the bottom of the glass. Replace the cover immediately and repeat the process until the required number of dishes has been prepared. When cool, the nutrient material which contains the food for bacteria should be a jelly.

Place a dish on a table in the laboratory and remove the cover, exposing the jelly for five minutes. Replace the cover and set the dish in a warm place. Examine daily. The spots which appear on the agar are colonies of bacteria, each having started with a single bacterium which fell upon the jelly at that point while the surface was exposed in the room. Test for the presence of bacteria in the air of the assembly hall, that of the corridor when classes are passing, of the living room at home, and of a park. Which is most effective in dusting, from a sanitary point of view—a feather duster, a dry cloth, or a damp cloth? Why are outdoor diversions to be preferred, in general, to spending leisure time indoors?

Suggested activity. Devise an experiment using petri dishes of nutrient agar to show that it is not only bad form to sneeze or cough in public without covering the nose and mouth with a handkerchief but that the practice is, besides, decidedly insanitary.

Exercise 66. To collect bread mold. Moisten a thin slice of rye bread with prune juice and fit it into a petri dish. Leave uncovered in the laboratory for fifteen minutes, then cover and set away in a moderately warm place for two or three days. Molds of various kinds, including bread mold, will probably be found growing on the bread from spores collected from the air of the room. Dark portions of the molds collected in this way are usually growths of bread mold. These can be picked out with a pair of fine-pointed forceps for use in starting a pure culture of bread mold in the following exercise.

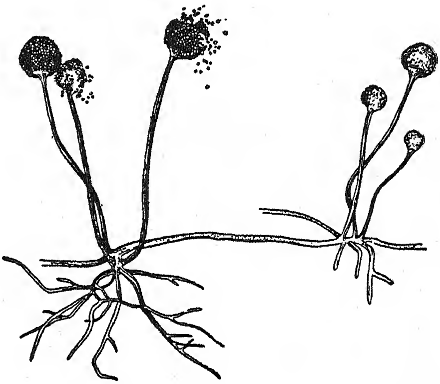

FIG. 38.—Drawing of a portion of a mycelium of bread mold (*Rhizopus nigricans*). The mold spreads over the surface of the food material by means of hyphae called stolons. Other hyphae, known as rhizoids, are special absorbing organs of the plant. The black knobs (white when young) are sporangia which bear asexual spores. They are supported by hyphae called sporangiophores (spore-sac-bearers).

Exercise 67. What is the nature of bread mold? Fit thin slices of rye bread into petri dishes. Cut a 1½-inch square of the bread out of the center of each dish, leaving a window through which the growing mold can be studied. Moisten the bread in the petri dish with prune juice, and transfer some of the mold of the previous exercise to the bread on two opposite sides of the window. Replace the cover and set the dishes away in a moderately warm place. Examine

frequently after the first twenty-four hours without removing the cover. As the mold grows out from the bread and across the window, it can be studied with a lens or by placing the dish bottom side up under the microscope, using the low power. Placing a few drops of prune juice on the portion of mold in the window to be studied, covering this with a cover-slip will permit a better view of the growing mold. Note that the separate threads (**hyphae**) are without cross walls and that they branch repeatedly. The whole mass of hyphae is a **mycelium.** The hyphae that grow along the surface of the bread are known as **stolons.** The knobs, at first white and later black, on the ends of hyphae extending out from the stolons are **sporangia.** These bear spores which ripen and are blown about by the wind, some of them reaching new sources of food where they may germinate and produce other mold plants. At the base of the sporangium-bearing hyphae are root-like hyphae (**rhizoids**) fitted by structure for going down into the medium (the bread) on which the mold is growing and from which it is absorbing food.

Write a summary giving the rôle of each of the three types of hyphae of bread mold which you have seen. In what two ways does bread mold spread to new sources of food? In what respects are spores better for distributing the plant than fragments of the mycelium?

Gametic reproduction. Under certain conditions a fourth type of hypha is produced by bread mold. It has been demonstrated that there are different, distinct strains of the plant. If a stolon of one strain grows near the stolon of another strain of the plant, special hyphae are sent out from the two stolons. These approach each other. When they come in contact, end to end, a special cell is formed in each. These cells fuse, making a single cell which forms about itself a heavy wall which protects the living material inside, and carries it through extended periods during which conditions are not favorable for growth of bread mold. The two cells which unite are called **gametes**, and the single cell formed from their union is a second kind of spore, a **zygospore.** Under favorable conditions, after a dormant period, the zygospore germinates and produces another plant. The type of reproduction involving gametes is known as gametic or sexual reproduction. Note the four types of hyphae shown in Fig. 39.

Exercise 68. Gametic reproduction in bread mold. To grow zygospores of bread mold. It is necessary to have a culture of a "plus" strain of *Rhizopus nigricans* and a culture of a "minus" strain of the mold. These can be bought from dealers in biological supplies. Prepare a petri dish with rye bread and prune juice as in Exercise 67. Using fine-pointed forceps, inoculate, with a streak of the "plus" strain and a streak of the "minus"

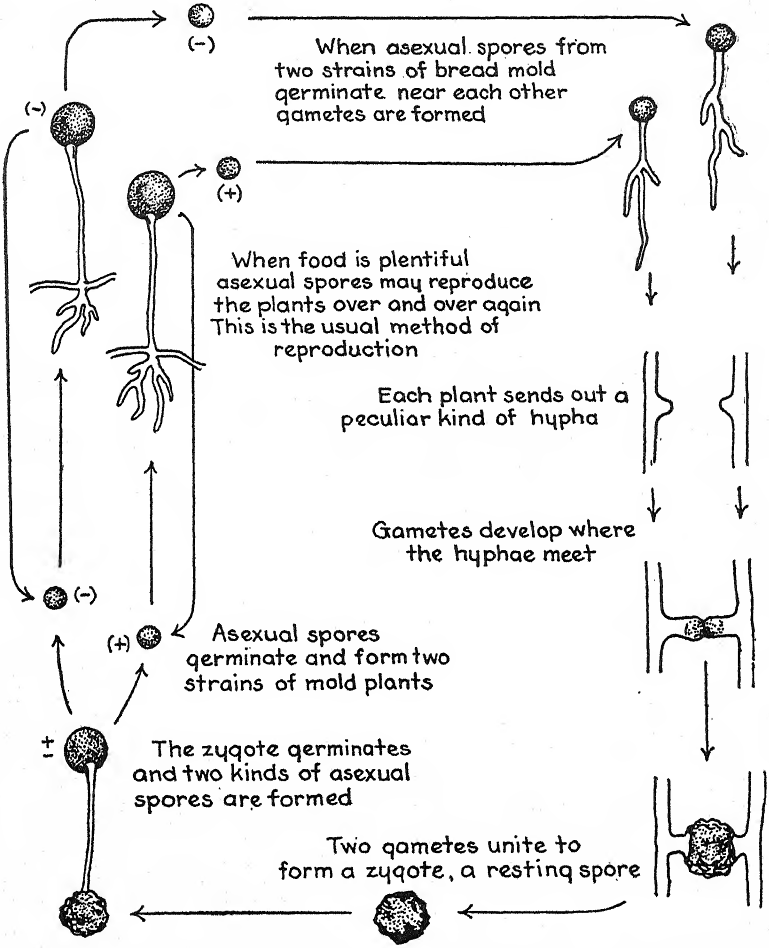

FIG. 39.—Life cycle of bread mold (*Rhizopus nigricans*). The usual method of reproduction of bread mold is by asexual spores. Under what conditions in nature may zygotes be formed? How could bread mold be distributed to new sources of food? By what two methods can a piece of bread be completely covered with mold as the result of the germination of a single asexual spore? What is a possible rôle of zygotes in the life cycle of bread mold? The union of two similar gametes resulting in the production of a zygote as it occurs in bread mold is a simple type of gametic reproduction known as conjugation.

strain, the surface of the bread on opposite sides of the window. Allow growth to continue for a week. Look for stages in the forming of zygospores in the window between the two streaks. Bits of this material may be easily lifted out and studied under the microscope.

How can bread mold use the nutrient materials on which it grows? From the action of enzymes produced by the rhizoids, complex food materials in the bread are broken down into simpler substances. In these simpler forms the nutrient materials can diffuse through the membranes of the rhizoids. Inside the plant these foods pass along the hyphae by diffusion. By oxidation of nutrient materials, energy is released. Thus the plant can carry on the necessary life processes. By assimilation, some of the nutrient materials become a part of the protoplasm, making it possible for the plant to grow.

Problem 5. How do parasitic plants cause plant diseases?

We have found that bread mold may cause the gradual breaking down of the chemical compounds which are found in bread or other nutrient substances which are non-living organic materials. *Rhizopus nigricans* and related molds may also become parasitic, invading living plant tissues and causing plant diseases, among which are certain rots of sweet potatoes, strawberries, apples, raspberries, and other plant products. Spores of *Rhizopus* are widely distributed, and every precaution must be taken by growers to avoid conditions which would be favorable for their invasion and growth in the food materials. As an example, sweet potatoes must not be bruised in handling, and they must be carefully dried and aired during the time that they are apt to heat and collect moisture in storage. Wrapping apples in paper tends to keep them dry and protects against invasion by *Rhizopus*, thus preventing apple rot from this cause.

Plant diseases caused by bacteria. The plant juices form favorable nutritive material for many bacteria. An acid condition of the sap may keep them out, as bacteria require a slightly alkaline or neutral medium. The juices of most plants, however, are suitable for the growth of these organisms. Bacteria may enter the host through wounds, or through openings, as stomata

and lenticels. The bacteria may cause injury to the host by invading the water-conducting vessels of the plant and cutting off the water supply, or by destroying soft tissues of the plant and producing blight or rot, or by stimulating the cells of the host to produce abnormal growths as knots or galls.

Fire blight. Where pears, apples, and quinces are grown it is quite common for branches of trees in full leaf to turn brown and

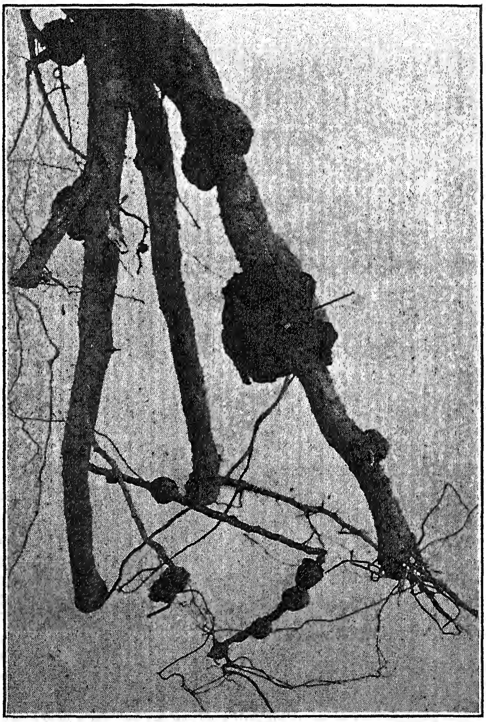

FIG. 40.—The large galls or warts are the result of infection by bacteria. The disease is known as crown-gall.

die. The disease causing this symptom is fire blight, a serious bacterial disease. It may attack the blossoms, causing blossom blight, or the leaves, causing leaf blight. It may also affect the twigs, larger branches, or main trunk of the tree. It affects pear trees more than any other and is sometimes called pear blight.

The cells of the soft tissues are invaded and killed by the bacteria. Measures for dealing with fire blight include control of insects, such as plant lice and other insects which carry the bacteria; cutting out infected parts of trees; and selection of varieties of fruit which are resistant to attack.

Diseases due to rust fungi. The common name, **rust,** of this group is suggested by the colored spores which are conspicuous in certain stages of the development of the parasite. The rusts cause disease in nearly all groups of economic plants: grains, grasses, orchard trees, garden vegetables, and forest trees. During the World War, when methods of greater food production and conservation were studied and carried out, a systematic attempt was made to eradicate wheat rust by ridding the country of its alternate host, the common barberry.

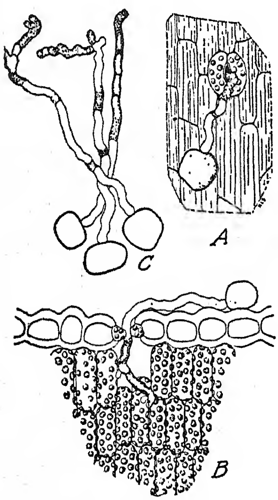

FIG. 41.—Germinating rust spores shown penetrating the tissues of a leaf by way of the stoma.

Stem rust of wheat. This is sometimes called black rust because of the black blotches which are found on the stem of wheat in certain stages of the disease. When the Chicago Board of Trade gets reports of extensive invasion of the wheat fields by black stem rust, there is usually an immediate rise of price of wheat. Why? The effect of rust may be slight, or almost a complete failure may result, depending upon the severity and time of attack. The damage to the host is caused by the loss of the food appropriated by the parasite and by the loss of water at the points where the epidermis is ruptured by the rust plant.

Life cycle of stem rust. A convenient place from which to start is the germination of the **teliospore,** the two-celled resting spore of the parasite, by means of which it goes through the winter. In the spring, under favorable conditions, each of the two cells of the teliospore gives rise to a short hypha from which four **sporidia**

(early spring spores) are loosed and blown away by the wind. These sporidia can not infect the wheat, and are lost unless they fall upon a leaf of the common barberry. The infection of the barberry leaf results in the production of **aeciospores** (late spring spores) which can not germinate on the barberry, but if blown to susceptible wheat, germinate and produce an infection. Reddish oblong spots, **uredinia**, soon appear with the production of large

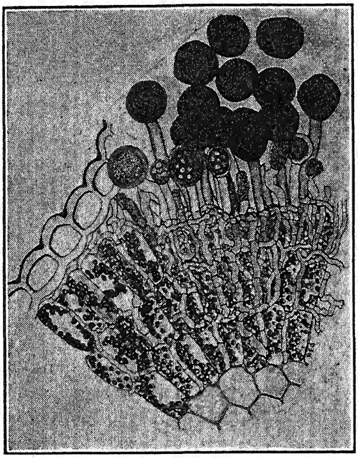

FIG. 42.—A portion of a wheat stem infested with the black stem rust. Observe the hyphae (threads) among the cells of the host, and the cluster of spores. These are the one-celled summer spores (urediniospores).

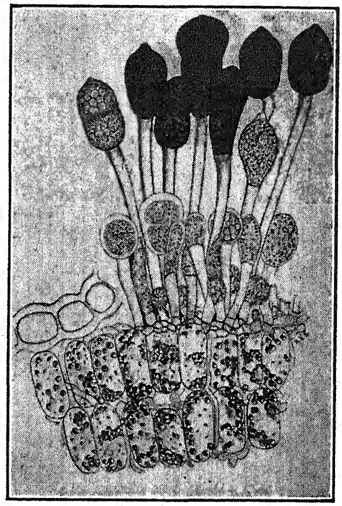

FIG. 43.—A portion of a wheat stem infested with the black stem rust. Observe the hyphae (threads) among the cells of the stem, and the cluster of spores. These are the two-celled winter or resting spores (teliospores).

numbers of the oval one-celled red summer spores of the rust, **urediniospores**. These spores are scattered by the wind to other plants of wheat, and thus the fungus is spread extensively during the growing season. Later, the urediniospores may be replaced on the same mycelium by the black or chestnut-brown two-celled winter spores, the **teliospores**. These are not capable of germinating at once but must pass through a dormant period. Thus they

are the resting cell of the fungus. Of what advantage is it to wheat rust to produce teliospores?

It is seen that the barberry is the intermediate host in the life cycle of stem rust of wheat when barberries are present, and the presence of the barberry is probably responsible for severe destructive attacks of stem rust. However, urediniospores may overwinter under certain mild winter conditions and be spread directly to the new crop of wheat plants.

The main methods of control of stem rust are (1) eradication of the common barberry, and (2) the selection and breeding of immune varieties of wheat. Denmark has eradicated the barberry, and black rust has almost disappeared. In Wales, where the barberry is still allowed to grow, there are serious losses of wheat each year from rust. Among resistant varieties of wheat, Kanred, a variety of winter wheat, and Black Persian, a spring strain, were found from extensive experiments, to be most promising.

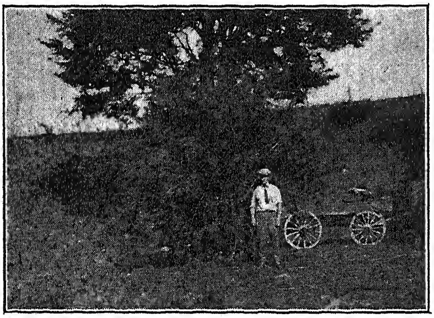

Fig. 44.—A large bush of common barberry, an alternate host for the black stem rust of wheat and other cereals.

Apple rust may be mentioned as another rust which normally requires an intermediate host for the completion of the life cycle. The infection of the apple leaves and fruit results in the production of **aeciospores**. These are blown to cedar trees, where they produce infection which results in the so-called cedar apples. The cedar apples develop spore horns which produce **teliospores**. These germinate, forming sporidia which are blown away and infect the leaves and fruit of the apple with the rust. In regions where there are cedar trees to be protected, cedar rust can be prevented by eradication of apple trees. In regions where apple growing is profitable, apple rust can be prevented by destruction of the cedar trees.

Stem rust of wheat and apple rust are examples of diseases

caused by fungi which have more than one host. This habit of life makes their control by man very difficult. Consequently they have become the worst enemies of certain crop plants.

Plant diseases due to smut fungi. Many plants among the cultivated cereals are affected by smuts. The parts most frequently destroyed are the grains or the flowers. As a result, every year there are heavy losses of cereal crops due to smut.

One of the most destructive diseases of wheat is stinking smut or bunt. Infection takes place in the young seedling stage, from spores carried on the seed. As a result of germination, infection threads are produced which penetrate the seedling and reach the growing point of the host. The fungus remains inside the host and gives little or no indication of its presence until the head of wheat emerges. Infected plants produce smut balls instead of grain. Since the disease is caused by an internal parasite, the smut plant is living at the expense of the host, consuming food, destroying seed, and retarding the normal life processes of the host.

Among other smuts which affect cereals are loose smut of wheat, loose smut of oats, and common corn smut. In the loose smuts of wheat and oats, the grains are destroyed. The smut which is formed in their place is loose and easily blown away. In corn smut, the usual symptom is the formation of small or large tumors on various aerial parts of the corn plant. At first, these are whitish, but later they become black owing to the development of spores. The membrane covering the mass breaks, and the millions of spores are released. The estimated annual loss in reduction of yield of the corn crop due to smut is 21 per cent. (See Fig. 5.)

Suggested activity. Make a collection of dry plant parts showing effects of plant parasites.

Problem 6. What are the principal groups of fungi?

As we have seen, fungi may be classified on the basis of nutrition into two main groups: saprophytes, forms which use nonliving organic food; and parasites, which obtain their energy and materials for growth from living hosts. We have also learned that some of the bacteria are autophytes, securing their energy from the oxidation of inorganic substances.

Bacteria. The **bacteria** represent the simplest fungi, being very minute, strictly single-celled forms.

Phycomycetes. The **Phycomycetes** or alga-like fungi usually have a mycelium composed of hyphae which are tubes and not made up of cells arranged end to end in filaments. In this respect they resemble certain algae, as *Vaucheria.* This group includes bread mold, certain blights, and many related forms. The late blight-fungus of the potato, a phycomycete, was responsible for the loss of the potato crop which resulted in the great Irish famine of 1845.

The white mold appearing on injured gold fish and frequently

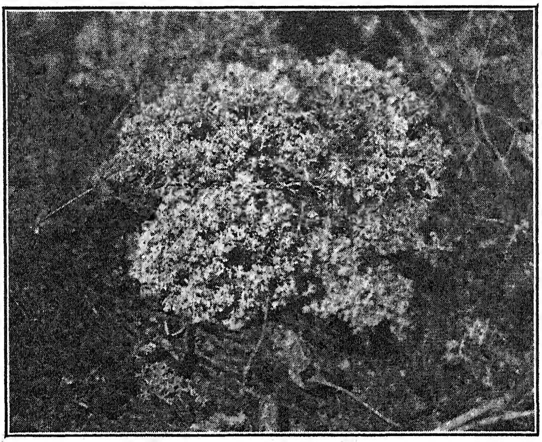

Fig. 45.—The reindeer lichen thrives in the tundra of the far north.

on young fish in hatcheries is a water mold, one of the alga-like fungi. The hyphae grow into the flesh of the fish, usually resulting in its death.

Ascomycetes. The **Ascomycetes, or sac fungi**, differ from the alga-like fungi in that they are made up of hyphae composed of separate cells. The common blue and green molds often seen growing on fruits are examples of this group. The **blue and green molds** are the most widely known of the molds which are destroyers of foods. Fruits, fresh and canned, bread, and even smoked meats are attacked. Molds of this group are used in the manufac-

ture of certain types of cheese to give them the desired flavor. These molds illustrate the characteristic of molds in general in being able to secure food and water from concentrated sugar solutions such as jellies and preserves. This property of the molds

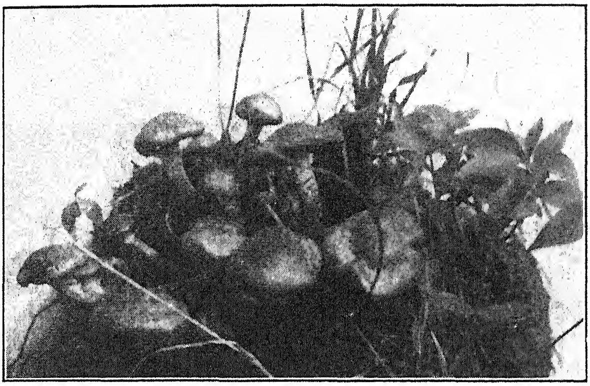

FIG. 46.—Mushrooms growing from an old stump of a tree.

results from the fact that the solution in the vacuole of the mold cell is comparatively highly concentrated.

Lichens. The greenish or grayish patches growing on rocks, trunks of trees, and sometimes on the ground, which are known as lichens, really represent two different plants living together. The two plants, one an alga made up of green spherical cells, and the other a fungus, live together in a symbiotic relationship. They are mutually beneficial. The alga makes food for itself and for the fungus. The fungus holds moisture which is used by the alga in the manufacture of food. Most lichen fungi are ascomycetes, bearing spores in sacs (asci) formed in brown cups or fruiting bodies appearing on the upper surface of the flat body of the lichen. Lichens are usually distributed by fragments of the lichen body.

FIG. 47.—Indian pipe, a saprophytic non-green seed plant.

A number of serious plant diseases are caused by parasitic Ascomycetes. Among these are peach leaf curl and brown rot of stone fruits.

Basidiomycetes or basidium fungi. The character which gives this group its name is the production of club-shaped hyphae or basidia which bear the spores. The group includes important parasitic and saprophytic forms. The rusts and smuts which affect grains, and the fungi which rot timber, are among the parasitic forms. Familiar saprophytes of the group are mushrooms, puffballs, earth stars, and stinkhorns. The part of the plant which attracts attention is really the fruiting body; the structures related directly to nutrition are hidden away in the substratum.

FIG. 48.—Dodder, a parasitic non-green seed plant. Growing on goldenrod stems.

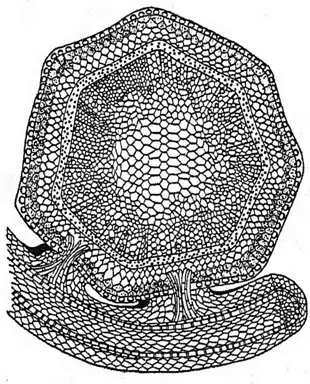

FIG. 49.—Cross-section of alfalfa stem and lengthwise section of a portion of dodder stem which is attached to the alfalfa stem by two haustoria. Dodder is a parasitic seed plant.

Aside from the rusts and smuts, most of the Basidiomycetes which are of economic importance are wood-destroying forms. Some of these are purely saprophytic, destroying posts, piling,

timbers, etc., which are continually moist and in contact with air. Others enter living trees through wounds, as those made in pruning or by hail or lightning. Infected trees may be greatly weakened by root rot or heart rot. The parasites are unable to advance into the active sapwood, and a tree may seem healthy from outward appearance even though its trunk may be hollow from the disintegration of the heartwood by wood-destroying organisms.

How do non-green seed plants obtain food? A number of seed plants without chlorophyll attach themselves to the roots of green plants and thus secure food which takes the plant through the complete cycle of flower-bearing and seed-producing above ground. The broom rape family includes the Indian pipe, pinesap, beech drops, and squaw root. Some of these plants are parasites growing in contact with roots of trees. Indian pipe and pinesap are saprophytic, non-green seed plants, getting their food from humus.

One of the most familiar of the parasitic seed plants without chlorophyll is the common dodder. The dodders are very close relatives of the morning-glory and sweet potato, although their resemblance is not evident to the casual observer. They have undergone marked changes due to their parasitic life. The seed germinates in the soil as does that of other seed plants. If the young seedling comes in contact with a suitable host, which may be a weed or a crop plant, it twines about the adopted plant, sending absorptive organs called **haustoria** into the tissues of the host. Manufactured foods are thus taken from the tissues of the host plant directly into the tissues of the parasite. Dodders are of considerable importance in various parts of the country as destructive parasites on clovers, alfalfa, sugar beets, and other cultivated plants.

ADDITIONAL QUESTIONS AND EXERCISES

1. What is the explanation for the fact that among seed plants we find an occasional white seedling?

2. Explain why a variegated plant is more likely to go down in the struggle in competition with all-green plants.

3. One use of food in animals is to supply a source of energy for physical exercise. Why do plants need an energy supply in the form of food?

4. We find large trees and small trees growing together in a forest. Explain

why the age of the forest can not be determined by counting the annual rings on the stumps of the largest trees.

5. Are the bacteria of decay the farmer's friends or his enemies?
6. Why are bruised fruits more likely to rot than sound fruits?
7. Why is it that bread dough, while rising, must be neither hot nor cold?
8. Why is the flavor of butter made from pasteurized cream more constant than that made from raw cream?
9. Why should canned fruit or vegetables be discarded without tasting if the ends of the tins are bulged outward before opening?
10. Explain why it is not safe to eat canned fruits which have mold on the top of the fruit, even though the molds are usually not poisonous.
11. How does smoke preserve meats?
12. Why is it that clover and other legumes do not grow well on acid soils?
13. In what way does a clover crop add to soil fertility?
14. In what respects may the widely distributed sweet clover be considered a beneficial weed?
15. What is meant by the nitrogen cycle in nature?
16. What is the carbon cycle?
17. Show the importance of the wide distribution of bacteria on the earth.
18. Explain why a deep well is usually better as a source of drinking water than a shallow well.
19. How can mold spores which are on the surface of fruit be prevented from germinating and causing rot?
20. Knowing what you do about molds, how would you store apples to prevent loss by rotting?
21. Make a spore print of a mushroom by placing the cap of the mushroom on paper, gill side down. Why is it necessary that such large numbers of spores are produced?
22. What are the disadvantages of the parasitic habit to the plant parasite itself?

REFERENCES

Bacteria, Yeasts, and Molds in the Home, by H. W. Conn, revised edition by H. J. Conn, 1932. 320 p. Published by Ginn and Company. Should be available for reference throughout the study of the unit. Useful and interesting facts about non-green plants that every student should know. Appendix with many easy experiments that may be performed by students who are able to do extra work.

Microbe Hunters, by Paul DeKruif. Revised edition. Published by Harcourt, Brace, 1926. Biographies. Interesting account in story form of the lives and work of Koch, Leeuwenhoek, Pasteur and others who were pioneers in the field of the relation of bacteria to disease.

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Who's Who Among the Microbes, by Wm. H. and Anna W. Williams. Published by the Century Company, New York, 1929. 302 pages, illustrated. The sketches in this book grew out of a series of radio talks on communicable diseases and their microbes. The authors have endeavored to describe "simply and accurately the most important facts known that help us determine how and why some microbes are harmful to man, others harmless and still others helpful." They also tell how man can use available knowledge to protect himself against harmful bacteria and utilize more fully the activities of the useful bacteria.

Bacteria in Relation to Man, by Jean Broadhurst, published by J. B. Lippincott Company, Philadelphia, 1925. 306 pages, 144 figures. A study-text in general microbiology, dealing with molds, bacteria, air, water, milk, soils, and human disease. At the end of chapters are excellent reference lists.

UNIT IV

GROWTH OF PLANTS

When a plant or animal **grows** it becomes not only **larger**, but also **different** in the structure and relationship of its organs, and in its behavior. That is, growth involves more than simple enlargement. When an acorn grows into the mighty oak, the full-grown tree is not merely the enlargement of a miniature oak concealed within the acorn. The mature tree possesses tissues and organs that did not exist in the acorn. Moreover, it has certain activities not carried on by the young plant. And, too, growth usually involves a change in the chemical composition of the plant. Growth then has two phases: (1) **increase in size**, due to increase in number and size of cells, and (2) **"a becoming-different,"** more technically called **differentiation**. This latter phase usually means an increase in complexity. The marvelous feature of growth is this differentiation—the development of a complex structure such as the oak tree with its roots, leaves, stems, flowers, fruits, and seeds, and the many different kinds of tissues which compose these various organs, from a few simple tissues in the acorn. But still more wonderful is the development of the miniature plant hidden within the seed from a single cell. The fundamental fact to keep in mind is that the adult plant is derived from a single cell. **The beginning of every plant is a single cell.** In seed plants this single cell is in a part of the flower called the **pistil.**

Not all parts of the plant grow at the same rate. For example, early in the germination of a bean seed the young root grows more rapidly than the stem. When a flower bud opens there is, for a short period, a very rapid growth of the flower organs.

Growth of a plant is the resultant of all its other activities. Every activity must progress normally if the plant is to grow properly. There must be absorption of mineral salts from the soil and of oxygen and carbon dioxide from the atmosphere; food man-

ufacture and respiration there must be; there must be adequate transportation of substances throughout the plant; and there must be food digestion and assimilation. Then we know that all these functions are influenced by certain environmental conditions such as temperature, moisture, light, the supply of raw materials for food manufacture, etc. The growth of a plant is, in many respects, like that of a boy or girl. Unless all functions of the body—

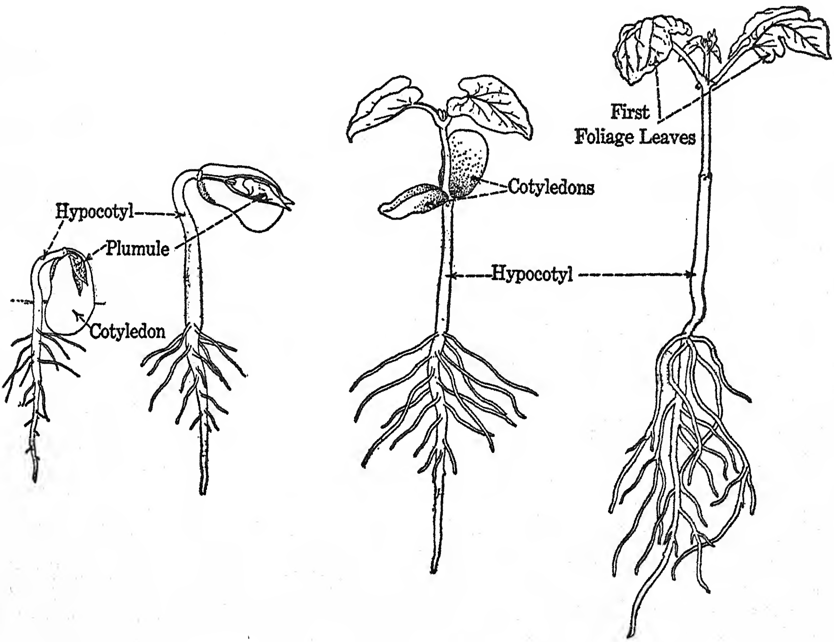

FIG. 50.—Successive stages in the germination of the seed of the bean. (From Holman and Robbins in Elements of Botany.)

respiration, digestion, assimilation, excretion, etc.—are normal, and unless the environmental conditions which control these functions are suitable, the boy or girl does not grow as he or she should.

Not all plants grow at the same rate. We recognize that it is the nature of some kinds of plants to grow more rapidly than others. For example, certain poplars attain a height of 15 to 20 feet within a few years, whereas slow-growing oaks may require

three or four times as many years to attain this height. Ordinary field corn grows to a height of 6 or 8 feet during the growing season, whereas certain dwarf varieties of corn under similar environmental conditions may attain a maximum height of not over 2 or 3 feet. We have learned that food is made in the chlorophyll-bearing cells. Leaves are the principal food-manufacturing organs. Do you think that the total leaf area of a plant has an influence on the rate of growth of a plant? Do you think that temperature, light, moisture, fertility of the soil, and other environmental conditions influence the rate of growth? Explain.

Problem 1. How do embryos grow?

The young, undeveloped plant as it exists in the seed is called an **embryo.** It is a simple structure with relatively few organs. For that reason, we say it is undifferentiated.

Exercise 69. Structure of embryo. Soak the seeds of beans, peas, squash, etc., in water. After they are softened, carefully remove the seed coats and separate the embryo. Each kind of embryo has a characteristic form, and certain organs. For example, in the bean embryo, notice the two large fleshy **cotyledons,** the very short, young **root,** the miniature **stem,** bearing two diminutive **leaves.** Compare the embryos of several different kinds of plants.

Development of the embryo following fertilization. We are familiar with the fact that **seeds are formed in flowers.** Seeds develop within a certain structure of the flower called the pistil. Long before the flower is open, there develops within its pistil one or more small masses of tissue, each of which is destined to become a seed. Among the cells of each mass of such tissue there is one cell, the so-called **egg cell,** which is destined to become the embryo—but only after it is fertilized. Fertilization consists in the union of the egg cell with a cell which is formed within the pollen grain. In other words, **fertilization involves the union of two living cells**—one developed in the pistil, the other developed in the anther. **The embryo begins its life as a single cell—the result of a union.**

This single cell—a fertilized egg cell—immediately divides and redivides. Soon protuberances, composed of groups of cells which are to become leaves, stem, and root, appear in the solid mass of cells. Then the seed coats harden, and the embryonic plant

ceases to grow, awaiting favorable conditions for resuming growth. The whole structure has now become a seed. Its essential structure is the **embryo.** Consider the oak tree again. We are accustomed to think that the plant begins its life at the time the seed germinates. This is not true. The embryo oak may have been resting for months or even years within the seed. **The very beginning of the individual oak tree is the fertilized egg cell.**

Problem 2. How does the plant cell grow?

We have learned that the plant body is composed of innumerable units called **cells.** **All many-celled living things grow by the multiplication and enlargement of their cells.** Each cell consists of a minute mass of living substance, or **protoplasm,** enclosed by a more or less rigid, non-living **wall.** The living substance has two main parts: an outer region, the **cytoplasm,** which probing with an extremely fine needle proves to be of about the consistency of glycerin; and an inner slightly less fluid region, the **nucleus,** which seems to control the activity of the whole. Both are surrounded by delicate membranes. Throughout the cytoplasm are small, clear, watery areas called **vacuoles,** which contain cell sap (water plus other substances in solution).

There are conspicuous differences between a young cell and an old cell. Near the growing point of any stem or root we can observe cells of different ages, and thus note the changes which they go through as they grow.

Exercise 70. Growth of cells in a root tip. Examine prepared, specially stained, lengthwise sections of a root tip. Observe the youngest cells at the growing point, and cells of increasing age farther and farther back from the growing point. Compare the cells observed with Fig. 51.

From the observations in this exercise we note the following very obvious changes in a growing cell: (1) enlargement, which is usually not equal in all directions; (2) increase in the size of the vacuoles, such that in an old cell the cytoplasm and nucleus merely line the inner surface of the cell wall; (3) in addition to these more obvious changes, there is often, in a growing cell, increase in thickness of the cell wall, and changes in the wall's structure and chemical composition.

Exercise 71. Differentiation. Examine the prepared slides of Exercise 70, and observe the different kinds of tissues distant from the growing point, that is, in the zone of **differentiation.** Here we see cells of many different sizes

and shapes, with differences in the thickness of walls and markings on the walls. Clearly, these cells are fitted to carry on different functions. A point worthy of special note is that all the different kinds of cells back of the growing point have been derived from the same kind of cells—those found at the growing point. In the development of growing-point cells, some have taken one course, some another; some have become conducting elements, others storage elements, etc. This is a process called **differentiation.**

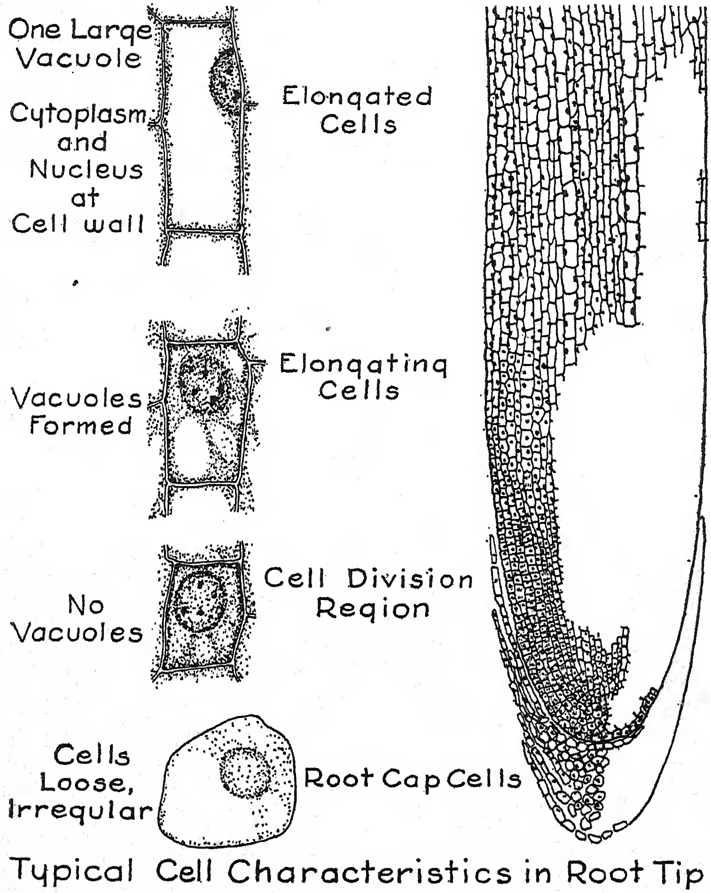

FIG. 51.—The root tip at right, cut in lengthwise section. At left are cells (enlarged) taken from different zones of the root. Note that the cells become older the farther they are from the region of cell division. Furthermore, observe the changes in the cells as they mature.

At the very growing point, in the region of active cell division, growth of a cell is soon followed by division of the cell. That is, a cell grows to a certain size, then divides into two similar cells, each resulting cell then doubling in size and dividing in two, and so on. The process of cell division is very complicated; it will be discussed in another chapter. Thus growth of this region involves both an increase in the size of cells and in the number of cells.

Problem 3. What is the nature of seed germination?

We have learned that **the essential part of a seed is the young plant—the embryo.** The plant in the embryo stage of its development may remain alive for years. That is, some seeds have a very great longevity. Under proper conditions of **moisture, temperature**, and **supply of oxygen**, the embryo starts to grow. This growth of the embryo, with the accompanying bursting of the seed coats, is called germination. **Seed germination is essentially the resumption of embryo growth.** Germination is completed when the young plant has developed far enough to lead an independent life, that is, does not derive nourishment from food stored within the seed. The food stored within the seed was obtained from the parent plant during the growing season.

Exercise 72. Water and germination. Place a number (100 to 200) of dry seeds of corn, radish, wheat, or other different kinds of seeds in glass tumblers or wide-mouthed bottles with a substratum of cloth, sand, paper, or sawdust that is barely moistened; in a second series, use soaked seeds, placing them on substrata saturated with water; in a third series, cover the dry seeds with water. Keep all at same temperature. Record your conclusion.

Water and germination. Water softens the seed coats and makes it possible for the young sprout to break through them more easily. Water also facilitates the entrance of oxygen into the seed, for when the seed coats are wet, oxygen will diffuse through them more readily than when they are dry, and too, carbon dioxide which is given off in the respiration of the living cells of the embryo can diffuse outward more easily. The secretion of digestive fluids, the digestion of stored foods, the movement of foods, in fact, **all activities of the cells of the seed proceed only when they are well filled with water.** Seeds which are old will not stand as much water as vigorous, fresh seeds. In handling old seeds, care must be taken to apply the water to them gradually and uniformly;

variations in the amount of water are injurious. **Seeds will endure greater extremes of temperature when they are dry than when moist.** Why?

Temperature and germination. No less essential than water to seed germination is a proper temperature. The temperature which is the most favorable to germination is not the same for the different kinds of seeds. It is quite well known that cucumbers and melons require a higher temperature to germinate properly than wheat, barley, and certain other small cereals. The seeds of "cool-season crops" such as peas, lettuce, radish, and small cereals, will germinate readily at 50° to 60° F., but corn, pumpkin, cucumber, eggplant, and other "warm-season crops" require a temperature of 70° to 80° F. to give fairly rapid germination. It requires from 10 to 12 days for corn grains to germinate at a temperature of 49° F., whereas at 80° F. they will germinate in 2 days.

The lowest temperature at which seeds can germinate is called the **minimum temperature**; the temperature at which they germinate quickest, the **optimum**; and the highest temperature at which they can germinate is the **maximum.** These three temperatures for a number of different kinds of seeds are shown in the following table:

	Minimum °F.	Optimum °F.	Maximum °F.
Barley	32–41	77–88	88–99
Clover (red)	32–41	88–99	99–111
Cucumber	60–65	88–99	111–112
Corn	41–51	99–111	111–122
Flax	31–41	77–88	88–99
Alfalfa	32–41	88–99	99–111
Melon	60–65	88–99	111–122
Oats	32–41	77–88	88–99
Pea	32–41	77–88	88–99
Rye	32–41	77–88	88–99
Wheat	32–41	77–88	88–108

From 60° to 80° F. is satisfactory for the germination of most seeds of temperate regions. The temperature of the soil is referred

to here, rather than the temperature of the air. When the soil is cold and moist, seeds should not be planted as deep as when it is warm and moderately dry. Why?

Exercise 73. Temperature and germination. Use petri dishes, or other dishes with cover, as germinators, and in the bottom of each place several

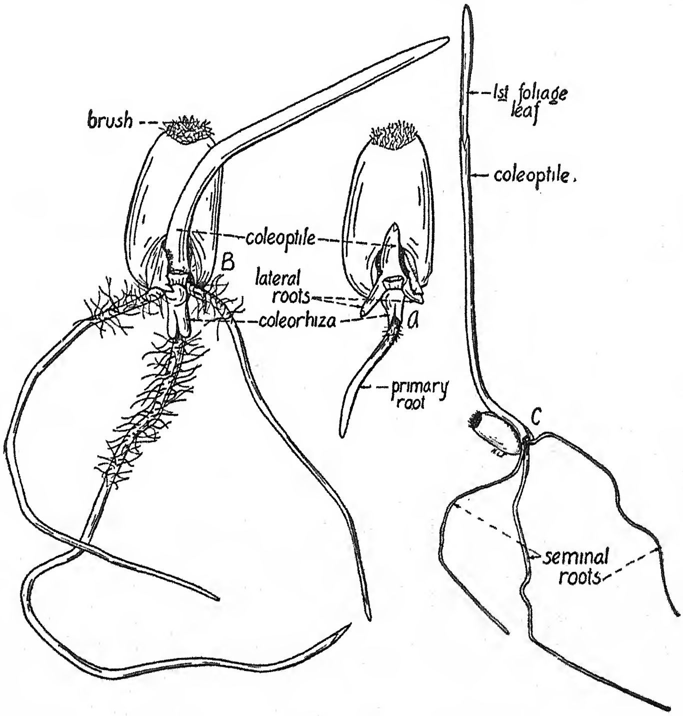

Fig. 52.—Three germinating stages in wheat. (From Robbins, in Botany of Crop Plants.)

thicknesses of filter paper or moist cloth. In each, place 100 lettuce seeds. Subject these lots to different temperatures ranging from 0° to 30° C. Keep a record of rate and percentage of germination. This exercise may be repeated using different kinds of seeds as desired. Draw conclusions.

Suggested activity. Place a half pint of soaked peas in a thermos bottle. Insert a thermometer down into the peas, and pack cotton into the neck of the bottle around the thermometer. Observe the reading of the thermometer as sprouting of the peas proceeds. Explain any increase in temperature.

Oxygen and germination. It must be kept in mind that **all living cells of the seed must respire in order to maintain life**, and that some oxygen is necessary in this process. In the resting stage the seed requires very small amounts of oxygen, but when germination starts it demands a greater amount. That germinating seeds respire actively is shown by the large quantities of carbon dioxide they give off, and also by the heat liberated in the process. A mass of germinating seeds of barley, or other seeds which germi-

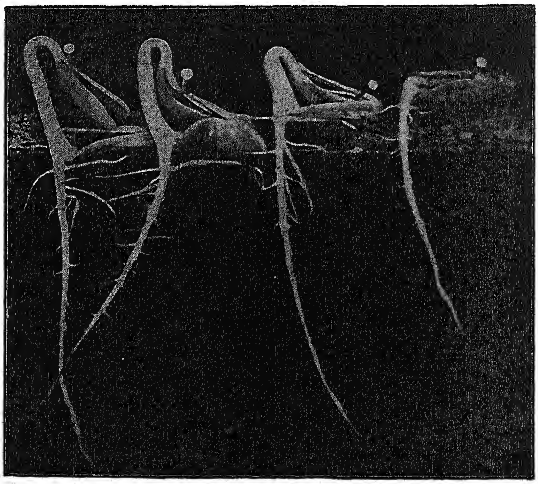

FIG. 53.—Germination of pumpkin (Big Tom) seeds, showing the pegs functioning in the removal of the coats. (After Crocker, Knight and Roberts, from Robbins, in Botany of Crop Plants.)

nate rapidly, may actually become heated until they feel warm to the hand. Even though there is sufficient water and warmth, unless seeds are planted so that free oxygen can reach them, they will not germinate. If seeds are planted too deep in a heavy clay soil, or in a soil that is too wet, they are quite likely to have a poor supply of oxygen and to germinate slowly. Explain why seeds should not be stored in air-tight containers.

Exercise 74. Oxygen and germination. Some seeds, those of rice for example, will germinate with a very small amount of oxygen, even with that which occurs in water. Place rice seeds in a beaker of ordinary tap water.

In a second tumbler place some boiled water, allow to cool, place rice seeds in the bottom, and cover the surface of the water with a thin film of oil to prevent the absorption of oxygen by the water. Record results. Explain.

Exercise 75. Process of germination. Observe stages in the germination of beans, peas, corn, squash, castor beans, or other seeds. Make comparisons. Examine each with regard to the **cotyledons**, the **root**, the **hypocotyl**, and the **plumule**. Which part first appears above the ground? Compare the growth of seedlings from which the cotyledons are removed soon after they come above ground with that of seedlings with the cotyledons intact. Test the cotyledons for starch. What is the function of the cotyledons? What is their fate?

FIG. 54.—Germinating seeds of mustard. The white cottony masses are root hairs on the primary roots.

Write descriptions of the stages of germination, comparing the different seedlings.

The process of germination. The first stage in the process of germination of the seed is the **absorption of water.** The rate at which seeds absorb water from soil depends chiefly upon the water content of the soil, the compactness of the soil, its temperature, and the character of the seed coats. A soil may be so dry that the seed does not absorb enough water to germinate, but remains in a dormant condition. Although a seed may absorb water very rapidly from a very wet soil, it will not necessarily grow so rapidly in such a soil. If a soil is excessively wet the oxygen supply

in it is low, and oxygen is as essential to the growth of the embryo as is water.

It is common practice to compact the soil over the seed after it is planted. This brings the moist particles close about the seeds and increases the points of contact between them. This object is attained by the use of the press wheel on planters.

Seeds absorb water more rapidly from a warm soil than from a cold one.

"Hard seeds." Although most seeds have coats which permit the ready intake of water, in some seeds, such as those of alfalfa, sweet clover, and other legumes, the coats may be almost impermeable to water. Such seeds are called "hard seeds." They will not grow readily, even when placed under perfect conditions for germination. Hard seeds are not necessarily poor seeds. Some of them will germinate in several weeks; some will remain in the ground for an indefinite period without germinating. Unhulled sweet clover seed may often have as much as 85 per cent hard seed. Hulled sweet clover has a lower percentage of hard seed than the unhulled. Why?

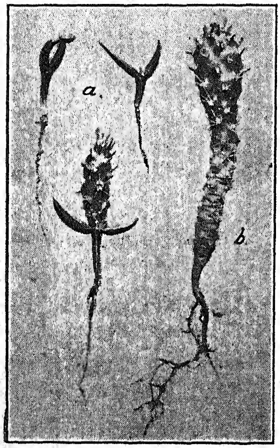

FIG. 55.—Stages in the development of a cactus plant. At the left, the cotyledons of the seedling are just breaking loose from the seed coats.

The permeability of seeds of legumes can be increased by "scarifying," that is, passing them through a machine that scratches the surface. The ordinary alfalfa huller is effective for this purpose, as is shown by experiments; alfalfa grown under a variety of soil and climatic conditions had about 90 per cent of hard seeds if hulled by hand, and only about 20 per cent if hulled by machine.

Digestion of stored food in seeds and its transfer. The second stage in the germination of the seed is the **digestion of stored foods,** and its **transfer** to the growing points of the young plant (embryo). Certain cells of the seed secrete digestive juices which act upon

the stored foods, render them soluble, and make possible their movement to the growing points of the roots and stem. As the young plant grows, the stored food in the seed is used up. It is

Fig. 56.—Germinating seeds between the folds of Canton flannel. Use two dinner plates, one inverted over the other. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

important to keep in mind that all the early growth of the young plant is made wholly at the expense of this stored food. However, not all the reserve food enters into the plant substance of the

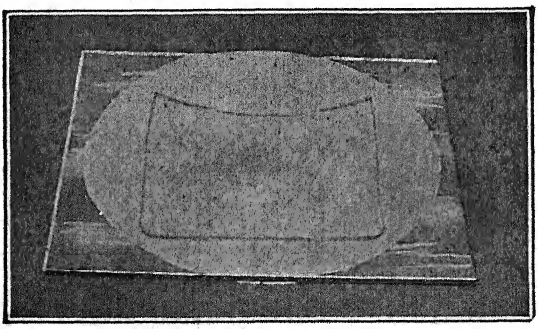

Fig. 57.—The seeds of bluegrass should be germinated on top of a blotter and kept in the light; cover the germinating dish with a plate of glass. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

seedling, but a portion of it is lost in respiration. It is not until the roots are established in the soil, and the leaves are green, that

the plant is capable of making its own food and leading an independent life.

Depth of planting seed. The depth at which a seed can be planted safely depends somewhat upon the amount of food stored within it. Many small seeds, such as those of tobacco and certain grasses, are planted on the soil surface; large ones may be planted more deeply. If a seed is planted so deeply that its reserve food supply is consumed before the plant reaches the light, the plant will die from starvation. Seeds should not be planted deeper than is necessary to insure a proper amount of moisture.

Growth of embryo. The swelling of the seed caused by the absorption of water, and the growth of the embryo, break open the

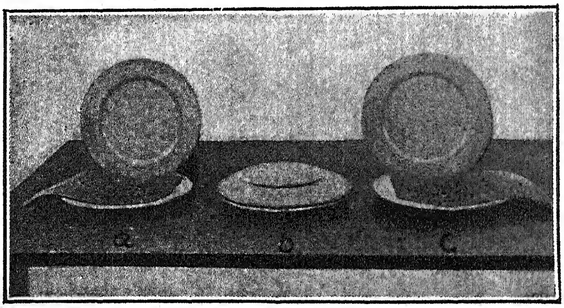

FIG. 58.—The dinner plate seed tester. (a) One hundred seeds are scattered on one-half of the blotter. The other half of the blotter is folded over the seeds. (b) Cover with another dinner plate, thus making a moist chamber. (c) The seeds have germinated, and the sprouts are ready to be counted. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

seed coat. The young root is usually the first part of the embryo to protrude. The cotyledons may remain in the soil or may be brought above the soil. The single cotyledon in all grains remains in the soil. The cotyledons of peas also remain underground. But in such seeds as bean and squash, the cotyledons are brought above ground and become the temporary leaves. Being exposed to the light, they may become green and aid in the food-making process. After a time, however, all the food that has been stored within them is absorbed by the growing seedling and they shortly wither and fall off.

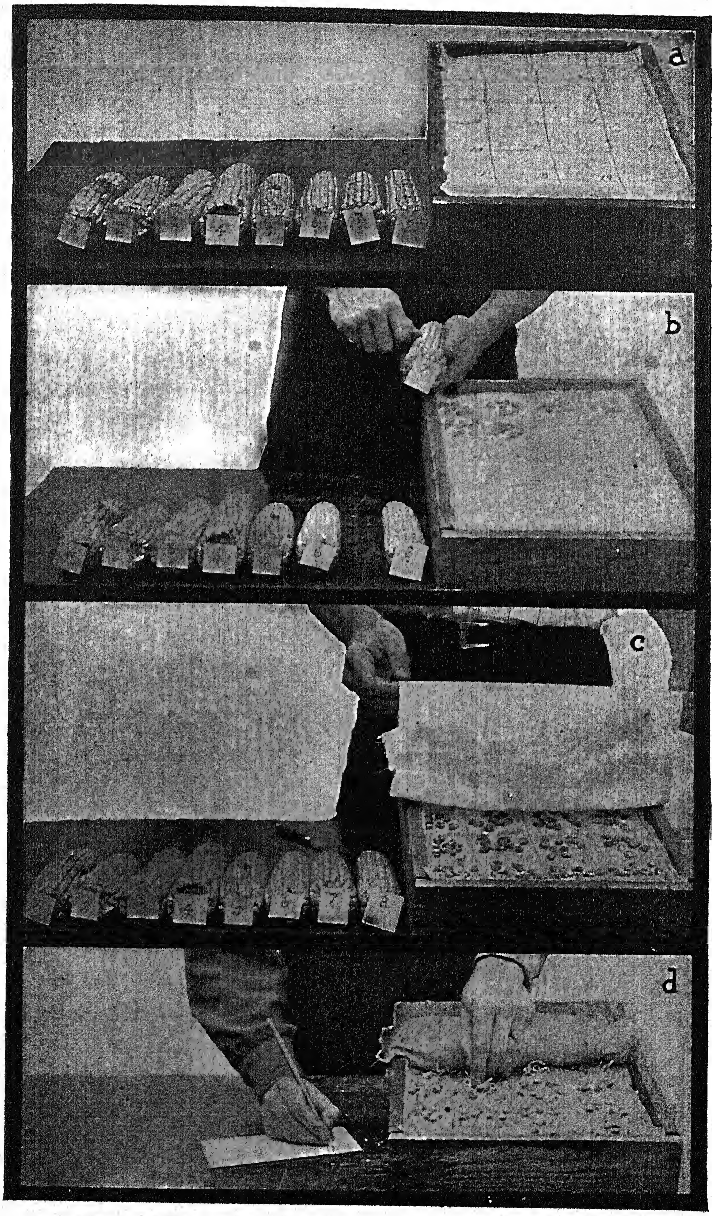

FIG. 59.—The soil flat or box tester, used in making individual ear tests of corn. (a) Number the squares on the cloth and ears to correspond; (b) place the kernels from individual ears on the squares; (c) cover the seeds with a second layer of Canton flannel, moisten, and cover with moist soil or sand; (d) at proper time remove the top cloth carefully, count and record the sprouts. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

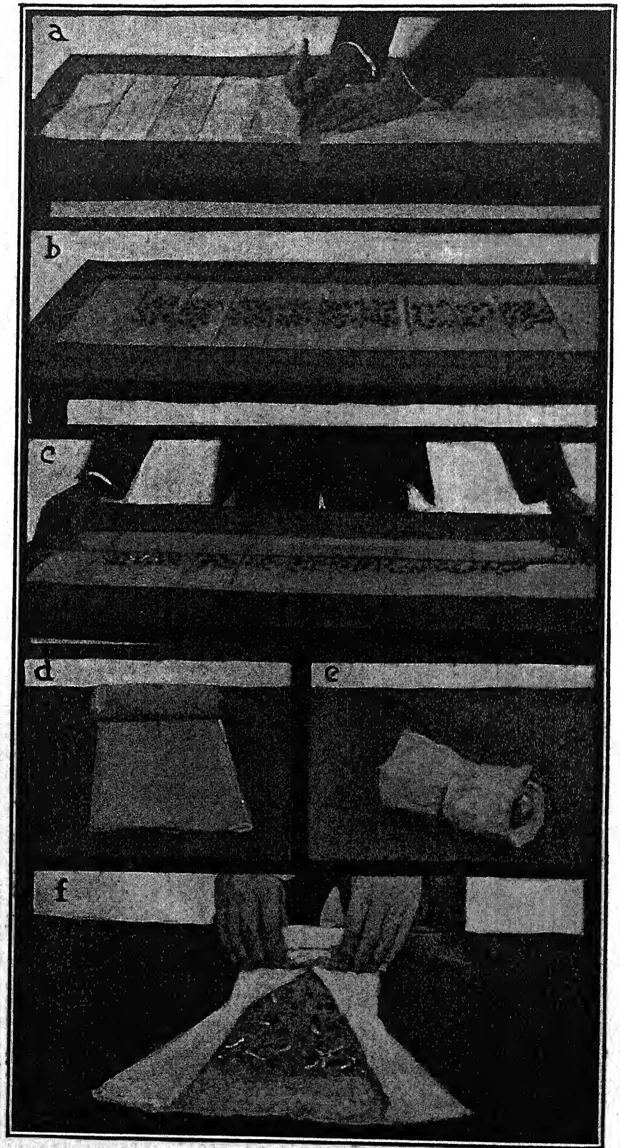

FIG. 60.—The rag doll tester, used in making individual ear tests of corn. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

Conditions affecting the vitality of seeds. It is a common observation that when a lot of seeds is planted under the most favorable conditions for germination a number of them fail to germinate. Some seeds are quick to germinate and form strong, vigorous seedlings. Others sprout but slowly, and the young plants are weak and sickly. The grower wants seeds which have a power to germinate readily and produce vigorous sprouts. In other words, he wants seeds of high vitality.

Many conditions have an influence on the vitality of seeds; they are discussed in the following paragraphs:

1. *Vigor of the parent plant.* Seeds from strong, vigorous parent plants usually have larger embryos and a greater amount of food reserve than those from weakly parent plants. In the selection of seed for planting, strong healthy mothers should be considered.

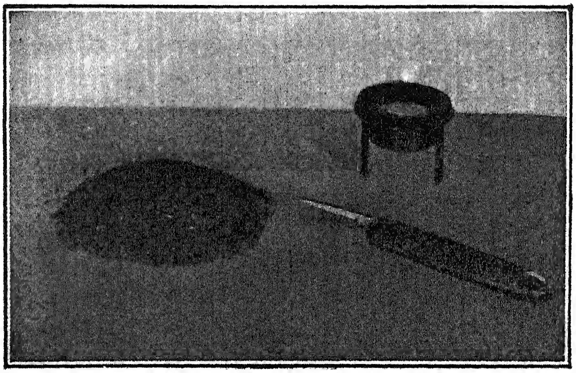

FIG. 61.—Making the purity test. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

2. *Conditions to which the seeds are exposed while developing.* The vitality of the seed is influenced by the temperature of the air and the amount of moisture in the air at the time the seed is maturing. Most seed mature best under dry atmospheric conditions, and with moderately high temperature. Low temperatures early in the autumn may injure the partly mature seed. Corn, for example, suffers from freezing before the grain is thoroughly

dry. The tissue of the grain is broken down by the freezing of the water in it. If the grain becomes thoroughly dried, it will withstand very low temperatures. Corn containing 13 per cent moisture may be stored with safety in bins exposed to temperatures much below freezing.

3. *Maturity of the seed.* Although seeds will often germinate when they are not fully ripe, the plants from such seeds are frequently weak. Lack of maturity or low vitality in corn is usually indicated by soft ears, by any discoloration of the grain, especially

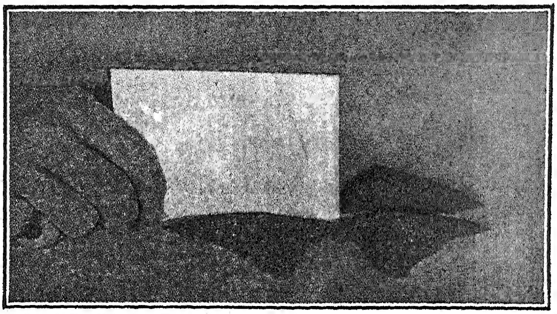

Fig. 62.—Showing the method of dividing the original sample in order to obtain the proper amount for purity analysis. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

at the tips, and by blisters on the skin. Immature corn quickly loses its germinating power.

4. *Conditions under which seeds are stored.* Seeds should be stored under conditions that are uniformly dry and cool. If the atmosphere is moist and warm, germination may be started; if it is, the respiration rate of the live cells is increased and the seed uses up a certain amount of its stored food. Its energy is thereby diminished. The seed may not have sufficient moisture and heat to germinate fully, but it will be kept in a greater state of activity than when in a completely dormant condition. Hence, its vitality is gradually being reduced. Moreover, in certain instances, seeds in bulk stored under moist, warm conditions may "heat" to such an extent that the embryos are actually killed by the high temperature.

5. *Age of seeds.* It is well known that seeds gradually lose their vitality as they grow older. The rate at which they lose their vitality depends upon the kind of seed and upon the conditions of storage. Seeds containing oil, such as corn and flax, lose their vitality much quicker than starch-bearing seeds, such as those of legumes. The seeds of legumes are noted for their great longevity. Some have been known to retain their vitality for 150 to 200 years. We hear the claim that wheat grains taken from the ancient tombs of Egypt will germinate. What is your opinion of this?

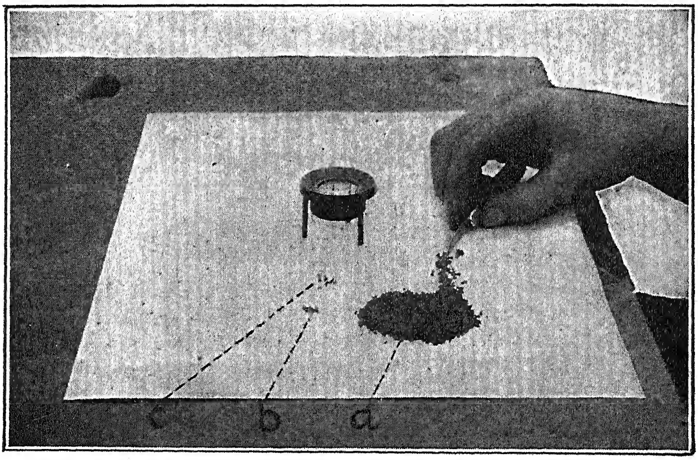

Fig. 63.—The purity test. With a knife and with the aid of a tripod lens the sample of seed is separated into three piles; (a) pure seed, (b) weeds and other foreign seeds, and (c) inert matter. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

Delay in the germination of seeds. The seeds of many plants have a rest or dormant period. That is, they will germinate better after a period of rest than they will when first mature. This dormancy is more common among wild plants than among domesticated ones. For example, wild oat seeds experience a delay in their germination, seldom germinating the year they are formed. The seeds of a number of weeds will lie in the ground for years in a dormant state. It has been shown that some seeds are still viable after 30 years' burial in the soil. Among such are the seeds of

pigweed, black mustard, shepherd's purse, common dock, green foxtail, and evening primrose.

There is an old saying that one year of seeds means seven years of weeds. A crop of seeds is borne; some of them may germinate immediately if the conditions are favorable; others may remain dormant for a year or two, and still others may remain dormant for five or six or more years. In cultivation, the seeds may be buried to such a depth that they do not get enough oxygen to germinate. Consequently, they lie dormant in the soil. Later, perchance, they may be turned to the surface in plowing and brought under conditions favorable to their germination.

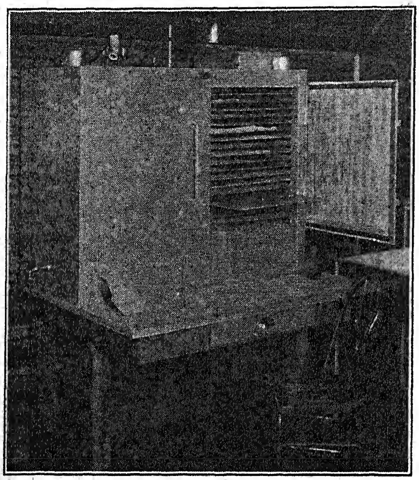

FIG. 64.—A common commercial type of seed germinator. The cloths or blotters holding the seeds are placed on the sliding trays. The germinator is heated by an electric plate and the temperature is controlled by a thermostat.

The delay in the germination of seeds may be due to several causes. Probably the most common cause is an **impervious seed coat** which prevents or retards the absorption of water. This topic was discussed on page 126. Another cause of dormancy is the inability of the embryo to break the seed coat. This is true of the common pigweed seed. As the seed lies in the ground, freezing and thawing and the action of soil organisms gradually soften the coats and make germination possible. Still another cause of seed dormancy is the inability of the embryo to germinate until it has gone through a series of changes known as "after-ripening." This process may be hastened in some instances by exposure of the seeds to low temperatures.

"Hard seeds" (see page 126), whose coats are impervious to

water, may be hastened in their germination by scratching the surface. The delay in the germination of olive seeds, which have a stony covering, may be overcome in part by soaking them in warm water, soaking in alkaline or acid solutions, or clipping the ends. Germination of some seeds may be hastened by soaking them in water before planting. For example, asparagus seed soaked a period of three to five days at a temperature of 75° to 85° F. will germinate more quickly than unsoaked seeds. The seeds of beets and lettuce have their germination hastened by soaking for a period of six hours in water.

Such hard-coated seeds as those of the peach, cherry, and walnut are often stratified in the early winter and permitted to freeze and thaw in order to break the seed coats. In stratifying seeds, alternate layers of sand and seeds are put in a box. They are then placed in a well-drained place and allowed to freeze. In mild climates where winter freezes seldom occur, the germination of many seeds is improved by stratifying them in a moist place; the moisture and the temperature fluctuations are probably responsible.

Suggested activity. Make rag doll seed testers according to methods given in farm bulletins and test corn grains from different ears obtained from various sources. What is the practical value of seed testing?

QUESTIONS

1. In what states has the vegetable and flower seed industry been developed extensively? Why?
2. Why have seeds of legumes, as a class, relatively great longevity?
3. What is the probable explanation of the belief that "wheat changes to cheat"?
4. Do you believe that all farmers should test, or have tested, their seed before planting? Give reasons.

Problem 4. How do stems grow in length?

In order to understand the manner in which stems grow in length, it will be necessary for us to be familiar with their external characters, and with the structure of buds.

Exercise 76. Twig characteristics. Examine a leafy twig of some woody plant, the cottonwood, for example. Observe that it is divided into sections

(internodes), and that at the enlarged joints (nodes) the leaves arise. Buds develop in the axils of the leaves, and also at the tip of the branch. The bud at the tip of the twig is called the **terminal bud.** Those along the side of the stem at regular intervals are **lateral buds.** The terminal bud develops the following spring into a branch, which, in turn, bears leaves. A lateral bud may be a **leaf** bud or a **flower** bud. If a leaf bud, it will develop into a side branch bearing leaves; if a flower bud, it will bear flowers.

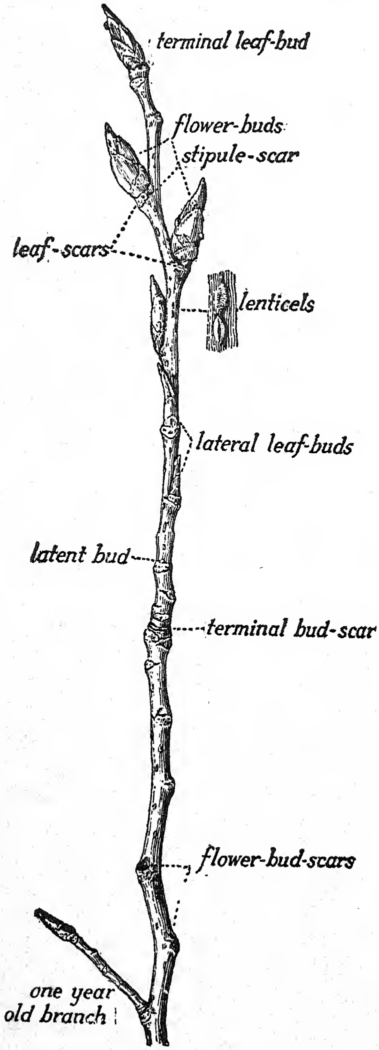

FIG. 65.—Cottonwood twig two years old. (After Longyear from Robbins, in Botany of Crop Plants.)

Exercise 77. The structure of buds. Make cross- and lengthwise sections of a large terminal bud. Note that it consists of a short axis, bearing small leaves. The outer leaves of the bud are called **scales;** they pro-

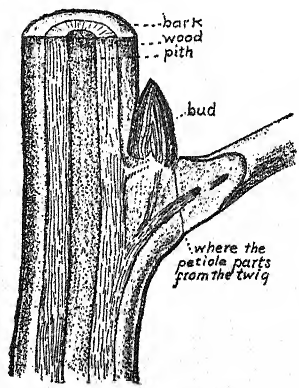

FIG. 66.—Section of stem showing a shedding leaf; also bark, wood, and pith are seen in cross- and longitudinal sections. (After Longyear, from Robbins, in Botany of Crop Plants.)

tect the soft, tender tissue within from drying out and from mechanical injury. The inner leaves are undeveloped foliage leaves.

Examine lengthwise sections of a terminal bud, made thin enough so that the structures may be studied with a compound microscope. At the very tip of the stem is a region made up of cells which are capable of **division**; back of this is a region in which the cells are rapidly **elongating**; then, farther back, is a region in which various stem tissues are **differentiating**; and still farther back is the **mature part** of the stem. It will be observed that within this bud there are very short internodes, and that the leaves come off at regular intervals, following identically the same arrangement as in the adult twig.

Exercise 78. Examine preserved specimens of twigs showing buds in the process of swelling and opening in early spring. What is happening to the young shoot which was hidden and protected by the scales of the bud during the winter? Explain why it is possible for a shoot to make such rapid development in early spring.

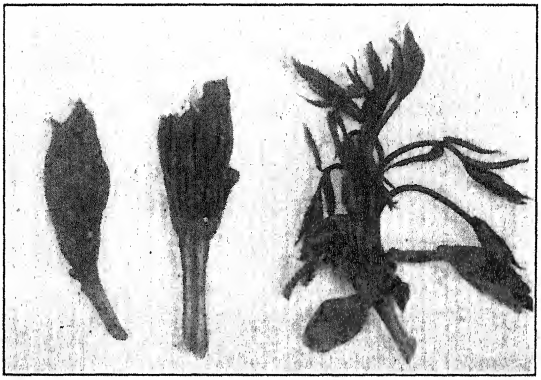

FIG. 67.—Growth as shown in opening buds of hickory. Left, opening bud; center, section of opening bud; right, growing shoot from a recently opened bud.

It is apparent from the above studies that a bud is simply an undeveloped stem. **A bud is a very short, young stem in which the internodes are exceedingly short.** The growing point of a stem, then, consists of a number of very much shortened internodes; **growth in length of the shoot consists in the lengthening of these internodes by increase in the number and the size of cells that compose internode tissue.** When a twig has made its year's growth, the internodes do not lengthen during subsequent years. Increase in length of that shoot is due to the addition of

other " joints " at the end. The fixed length of old internodes is well proved by the common observation that nails driven into the trunk of a tree, or a branch, are not elevated above the ground as the tree grows. If, when you were a young boy, you carved your initials deep in the bark of the old tree that grew by the swimming hole, those initials, although probably partly obliterated by the growth of bark, are today at the same distance above the ground as they were the day you carved them. A common impression prevails that, in pruning, the branches of a young tree should

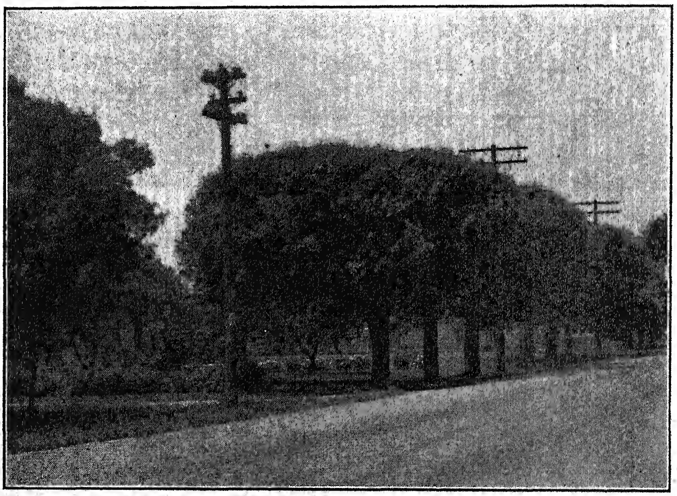

FIG. 68.—The beauty of our landscapes is being marred by tree-butchery, such as is shown here.

be started low to the ground, so that they will be at about the proper elevation above the ground when the tree reaches maturity. The errroneous supposition here is that the limbs are raised by the growth of the tree.

Problem 5. How do stems grow in diameter?

Exercise 79. Structure of the woody stem. With a safety razor blade cut thin cross-sections of a one-year old woody stem, such as a twig of the cottonwood, box elder, cherry, or apple. Note the three principal regions: the

bark, the **wood**, and the **pith**. The bark can be separated from the wood. It separates from the wood along a region known as the **cambium**. The cambium is composed of thin-walled, tender cells, capable of rapid division and growth. **The cambium is the growing layer of the stem.** (See p. 64).

The **bark** is covered with a corky layer which successfully prevents the rapid loss of water from the stem. Beneath the corky layer of the bark are several layers of cells containing chlorophyll, and hence capable of manufacturing sugar. The inner part of the bark is the **phloem.** The phloem is that portion of the stem which

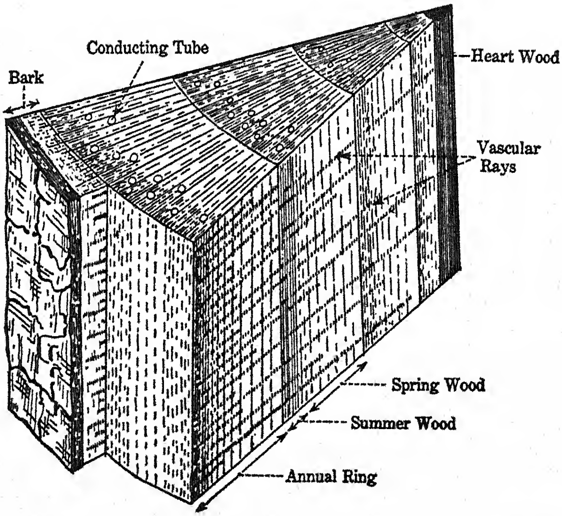

FIG. 69.—Portion of a four-year-old stem of the pine, shown in transverse, radial, and tangential views. (Redrawn from Strasburger.)

is largely concerned in the conduction **downward** of foods manufactured in the leaves (probably mineral substances and foods **upward**, also). Large tubes, known as **sieve tubes**, in the phloem are the conducting elements. In addition to cork, chlorophyll-bearing tissue, and phloem or food-conducting tissue, the bark may have fibers and other cells which give strength.

The **wood** of the stem is made up chiefly of large conducting tubes or vessels, fibers, and storage cells. It is in the vessels that water (and probably salts and foods, also) is carried. The fibers

give strength to the stem. The storage cells store water and foods, and may also conduct these substances short distances.

The **pith** of the stem consists of a group of large, thin-walled cells which store food to some extent. The amount of pith in stems varies greatly.

Radiating from the pith, and extending through the wood and the phloem part of the bark, are rows of cells which constitute the

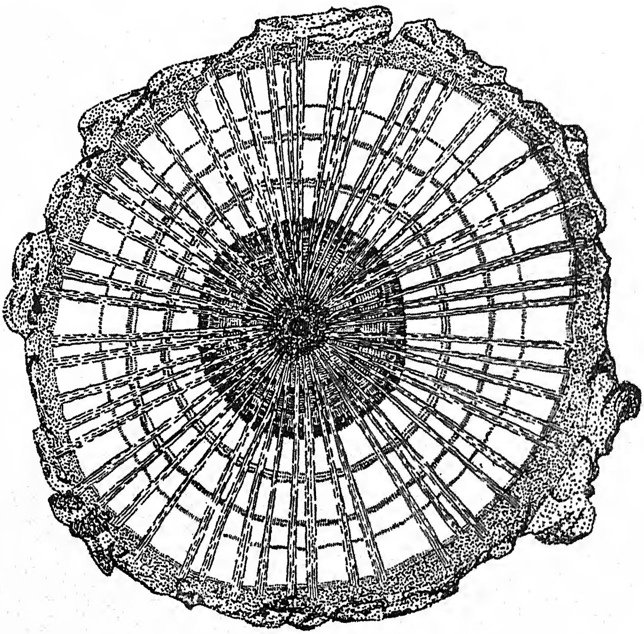

Fig. 70.—Cross-section of six-year-old woody stem. Note the dark-colored heartwood, light-colored sapwood, bark (dotted) and vascular rays.

vascular rays. Water, salts, and foods are carried radially in these ray cells; they also serve as places of food storage. If a cross-section of a twig is treated with iodine, starch, which is stained blue, is seen to occur chiefly in the vascular rays and in the outer cells of the pith.

Exercise 80. Structure of woody stem—two years old. Cut sections as in Exercise 79, but of two-year-old twigs. Compare with the one-year-old

stem. With a hand lens determine the number of rings of growth of wood. Note the "pores," the vessels as seen in cross-section. (Fig. 31).

In stems of the type to which our common orchard trees belong, there is a continuous **cambium** layer between the bark and the wood. The cambium cells divide and redivide, adding to the bark cells on the outside and to the wood cells on the inside. Hence, by a division of cambium cells, new phloem is laid down on the **inside** of old phloem, and new wood is laid down on the **outside** of the old wood. A layer of phloem and a layer of wood are formed each year. The phloem rings are less distinct than those of the wood, and as the stem grows older the older phloem may peel off with other bark tissue.

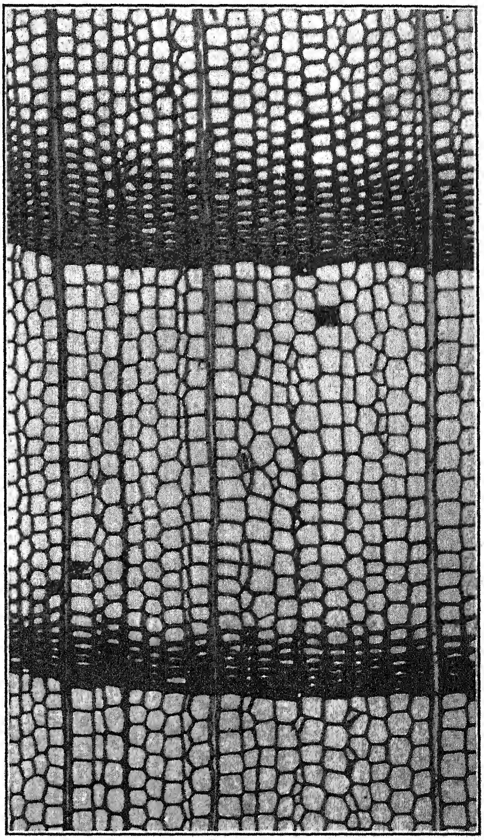

FIG. 71.—Cross-section of a portion of pine wood. One complete annual ring (center), and parts of two other annual rings (above and below) are shown. The narrow, dark part of the annual ring is "summer wood," the broad, light part, "spring wood."

Annual rings of growth. An annual ring, as generally understood, is **one year's growth of wood.** The ring varies in width, depending upon the time in the life of the plant it was formed, and upon seasonal and climatic conditions. Furthermore, it is known that some

trees grow rapidly, producing wide annual rings, whereas it is a specific character of others to grow slowly, i.e., produce narrow rings. The amount of carbohydrates supplied by the leaves and the water supply are two chief factors determining the width of rings.

There is usually a marked difference in the wood formed in the spring and early summer and that produced in late summer and fall. In early or so-called **spring wood,** conducting tubes are large and quite numerous; in late or **summer wood,** conducting tubes are smaller and fewer, and wood fibers are relatively more abundant. Hence, summer wood has more strength than spring wood. The summer wood of one year (say 1925) is adjacent to the spring wood of the following year (1926).

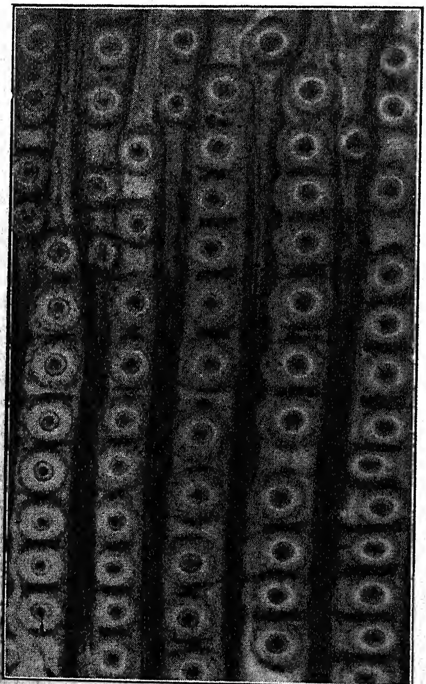

FIG. 72.—A portion of pine wood cut lengthwise, showing the conspicuous, circular bordered pits in the walls of tracheids.

Soft wood is usually one from a tree which grows rapidly. The conducting tubes are rather small and uniform in size and evenly distributed throughout the year's growth. **Hard wood** is usually a comparatively slow-growing wood. The conducting tubes of the spring and early summer are large and numerous, but the autumn wood is solid as a consequence of the greater abundance of strengthening elements.

Exercise 81. Determining the age of trees. Using a freshly cut stump or log, attempt to determine the age of a tree. If the rings of growth are

counted on a stump three feet high, does this represent the true age of the tree? Why? Can we always rely absolutely upon the number of rings in determining the age of a tree? Why?

Cork. Usually when we speak about the growth in diameter of a woody stem, we refer to the annual rings of **wood**, that is, of tissue inside the cambium. The bark also develops annual layers but they are much thinner than those in the wood and generally are broken and split off. Also, woody plants develop a cambium, known as **cork cambium,** which usually originates in the cortex. This cambium forms **cork** to the outside and cortex to the inside. In some plants, notably the cork oak of commerce, the layers of cork, formed year after year, adhere to the tree, and we observe them as definite annual layers of growth. Cork cells have walls which are impregnated with a fatty substance known as **suberin,** which is impervious to water.

Summarizing, the growth in diameter of a woody stem is due to the activity of **two cambiums**: (1) the **vascular cambium** which lies between the wood and bark; this adds new rings of growth of wood to the **outside** of the old wood, and new bark tissue to the **inside** of the old bark; (2) the **cork cambium**, situated in the bark; this adds layers of cork to the **inside** of old cork, and cortex tissue to the **outside** of old cortex. In most woody plants there is a gradual peeling off of the bark, which includes tissues arising from both cambiums.

Suggested activities. (*a*) Find out by inquiry and from books on horticulture how fruit trees are grafted, and prepare a report to be read to the class. Explain why it is necessary to bring the cambiums of stock and scion into contact. Include in your report a description of "budding" as done by fruit-growers.

Problem 6. How do roots grow?

In Problem 2, Exercises 70 and 71, we examined young roots and found that the growth in length of a root is near the tip. This may be ascertained by the following simple experiment.

Exercise 82. Method of growth in length of a root. Germinate horse beans or lima beans on moist cloth or filter paper in a covered dish. When the first root is 1 or 2 inches long, carefully mark with lines of India ink, 1 mm. apart, beginning at the tip and extending backwards 2 or 3 cm. After 24

hours, observe. Which marks are the farthest apart? Draw conclusions as to the regions of growth.

The **growing point,** which includes cells capable of division and growth, is some distance from the root tip, being covered and protected by a root cap. Immediately back of the growing point, the cells are elongating, and still farther back the cells are differentiating. As a matter of fact, the growth in length of a root is confined to the growing point and region of elongation, these two regions together usually being not more than $\frac{1}{4}$ to $\frac{1}{2}$ inch long. A root is not pushed through the ground by growth of cells far removed from the tip. Rather, by the addition of new cells immediately behind the protective root cap, and their elongation, the root tip finds its way between the particles of soil. There are no joints in the root as there are in the stem. Why is it practically impossible for a root to pursue a straight course through the soil?

The growth in diameter of the roots of perennial plants is similar to that in the stems. An old root of our common trees and shrubs has annual rings, and very much the same structure and appearance as an old stem. Can you cite an example of the lifting power of roots?

Problem 7. How do leaves grow?

We know that leaves grow very rapidly in the spring. After a few warm days, the entire tree appears green, and in two or three weeks leaves have attained their maximum size for the season. It must be that leaves are fairly well formed in the bud. This fact is well demonstrated by the following exercise.

Exercise 83. The growth of leaves. Remove the scales from winter leaf buds of several different kinds of deciduous plants and carefully dissect out the young foliage leaves, observing whether they are rolled, folded, or plaited. Spread these young leaves out flat, examine with binoculars, and observe that even in the bud the leaves have veins, and very much the form they will have when fully grown.

From these observations we are led to conclude that the leaves of our common temperate-climate deciduous plants are formed the season before their expansion. When the bud breaks open in the

spring, the leaves grow very rapidly, attaining full size within two or three weeks.

We have learned that stems and roots grow in length chiefly at or very near the tip. There is a very unequal rate of growth in different parts of these organs. Not so with leaves, as is shown by the following exercise:

FIG. 73.—A single fern leaf unrolling.

Exercise 84. The growth of leaves. With a leaf-marker (rubber stamp marked into millimeter squares) stamp a young leaf, ½ to 1 inch in width. After the leaf has attained full size, observe the size and shape of the squares. If throughout the leaf the squares have maintained their shape, it is an indication that growth has been at an equal rate throughout all portions of the leaf. As a matter of fact, growth of the leaf after it breaks from the bud is simple enlargement of cells already formed; additional cells are not developed.

Thus far we have not accounted for the growth and development of leaves in the bud. From Exercise 77, we learned that the stem growing point consists of a very short axis with nodes and extremely short internodes. The nodes are the places on the stem where the leaves arise. In the lengthwise sections studied in the above exercise, we observed slight protuberances near the growing point, which consisted of groups of cells, each destined to become a leaf. Each group of cells finally enlarges and takes on the form of a leaf, which rests in the bud stage until the spring of the following year.

Problem 8. How do seeds and fruits grow?

In the discussion of Problem 1, it was pointed out that seeds develop within a certain structure of the flower known as the pistil, and that long before the flower opens there develops within the pistil one or more small masses of tissue, each of which is des-

tined to become a seed. These masses of tissue are called **ovules.** The ovule is a small spherical or egg-shaped structure in the ovary of the pistil. It is attached to the ovary by a short stalk, which becomes the stalk of the seed. The mature ovule, just before fertilization, consists of a central mass of tissue, surrounded by one or two coats which become the protective coats about the mature seed. These fit closely about the ovule, except at one point, where there is a very small opening, the **micropyle.** See p. 154.

Within the central mass of tissue is the **embryo sac,** the structure in which the embryo or young plant develops. The mature embryo sac commonly has eight nuclei, one of which, after fertilization, develops into the embryo plant; two others unite with a second nucleus from the pollen tube, and the resulting body develops into **endosperm,** which is a food supply surrounding the embryo. The remaining five nuclei usually soon disappear, being absorbed or disintegrating.

Pollen grains play a part in the formation of fruit. They are a product of the anthers. At maturity, the anthers split open and the pollen grains are distributed. The pollen grains of plants vary widely in form, size, color, and particularly in surface markings. The wall of the grain usually consists of two coats, an outer thick one and an inner thin one. The wall encloses a mass of protoplasm, the essential parts of which are **three nuclei.** One of these, the **tube nucleus,** plays a part in the growth of the pollen tube; the other two, **sperm nuclei,** fertilize certain nuclei in the ovule.

Ferilization. The pollen grain is usually brought to the stigma by wind or insects. It absorbs water and nutrient materials from the surface of the stigma, and grows by sending out a tube, known as the **pollen tube**. The pollen tube grows downward through the stigma and style and finally reaches the ovule. It goes through the micropyle and penetrates the ovule tissue. After the dissolving of the wall at the tip of the pollen tube, the three nuclei are discharged into the embryo sac. The tube nucleus is absorbed. One sperm nucleus unites with the egg or female nucleus to form the **fertilized egg**. Thus, this nuclear mass contains determiners for characters from the plant furnishing the pollen (paternal characters) and also those from the plant fertilized (maternal characters). The union of the sperm nucleus of the pollen tube with the

egg nucleus of the embryo sac is **fertilization.** The fertilized egg nucleus now develops into a young plant (embryo).

In cereals and lilies and a number of other plants, so-called **double fertilization** has been observed. One sperm nucleus has been accounted for as uniting with the embryo nucleus. The other unites with the two so-called polar nuclei of the embryo sac. The body resulting from this union also carries determiners for both maternal and paternal characters. It develops into the endosperm of the seed.

Immediately following fertilization, there is a series of changes not only in the ovule, resulting in a seed, but in the ovary wall as well. Normally, if the egg nucleus is not fertilized the ovule does not develop, but withers and dies.

Just one pollen tube penetrates the embryo sac to bring about fertilization. Many pollen tubes, even hundreds, may grow down the style, although comparatively few may function. Those which do not, wither and die. We may be sure that every ovule that develops into a seed has been visited by at least one pollen tube, and that only one pollen tube has functioned there.

Summarizing: The seed develops from the ovule in the ovary, but ordinarily only after fertilization. After fertilization, the embryo or young plant develops from the egg nucleus, the endosperm develops from other nuclei in the embryo sac, the ovule coats harden to form the seed coats, certain tissues disintegrate, and the whole resulting structure we call a **seed.** The **fruit** is the matured ovary, with its seeds, and any other part of the flower which may be closely associated with it. The fruit contains the seed or seeds. For example, the entire bean pod is a fruit; the beans within are the seeds. It is often difficult to realize that a large fleshy fruit, such as a tomato, is derived from the ovary. The walls and partitions of the ovary enlarge greatly to form the mature fruit. But, throughout all the changes which occur during the development of the tomato fruit from a small structure much less than $\frac{1}{2}$ inch in diameter to the large tomato, there is very little increase in the number of cells; rather, simple enlargement of cells already formed, coupled with chemical and physical changes which affect texture, color, flavor, and edibility.

QUESTIONS

1. What is the force which pushes young roots through the soil?

2. How do cells of the young root change to vessels and tubes as the root grows older?

3. Why is it that moist soil should be packed about seeds that are planted?

4. Explain why plants in clay soil should never be cultivated when the soil is wet.

5. Explain why corn is cultivated by digging the soil deeply at first, whereas shallow cultivation is used around older plants.

6. Why should seeds never be planted in soil which is either very dry or very wet?

7. Give two reasons why oats should be planted earlier in the season than corn.

8. Explain why only the tips of asparagus shoots are tender.

9. Why is the bark of tree trunks usually ridged?

10. Why is the surface of twigs of a tree more smooth than that of the trunk?

11. If it requires 30 feet of rope to make a swing by tying the two ends to a branch of a tree, what length of rope will be required for a swing attached to the same branch 30 years later, the tree having increased in height 20 feet during the period?

12. In what two ways can you tell the age of a twig?

13. Why is the bark of a tree thinner than the wood?

14. Explain the appearance of the grain of lumber.

15. Explain why it is possible for rabbits to kill young trees by gnawing the bark from a ring around the base.

UNIT V

REPRODUCTION OF PLANTS

Reproduction is one of the fundamental characteristics of life. Reproduction is race preservation. It is a process which occurs not only in animals, but also in all plants—in trees and shrubs and herbs, in toadstools and ferns, bacteria and seaweeds—in short, in every kind of plant existing on the surface of the earth. It is a process which, in the broadest sense, involves the production of new individuals, by any method whatsoever.

An individual plant is designed to function not only for itself, but also for the race to which it belongs, to sacrifice all or a part of itself in propagating the species.

All life comes from pre-existing life. The new organism is nothing more or less than a piece of living material separated from its parents. Living things as we know them originate only by reproduction. Even the tiniest germ visible with the most powerful microscope must have ancestors. Fossil remains bear witness that millions of years ago, in the waters of ancient seas, life first appeared. From that day to this there seems to have been an **unbroken continuity in the chain of living things.**

There are two general methods of reproduction of plants, namely, **asexual reproduction and sexual reproduction.** When you divide dahlia roots, or start "slips" and cuttings from roses and other woody plants, you are reproducing these plants **asexually**, that is, without sex. Many of the primitive plants, such as the bacteria, reproduce by asexual means alone. With them, sexual reproduction is unknown. **Sexual reproduction in plants involves the union of parts of two parents—the egg of the female plant and the sperm of the male plant—to form a new individual.** All eggs and sperms are cells—minute units of living substance or protoplasm. The cell resulting from the union of the egg and sperm grows into a mature plant. **The cell is the unit of reproduction.**

Problem 1. How do flowering plants reproduce?

In the higher plants, including cultivated plants of all kinds, **the flower is the organ of sexual reproduction.** It is in the flower that the seed is developed. Primarily the flowers are organs of seed production. Many flowering plants can be multiplied by means of vegetative organs, such as stems, roots, and sometimes leaves, but the principal way in which they multiply is by means of seeds, which are a product of the flower.

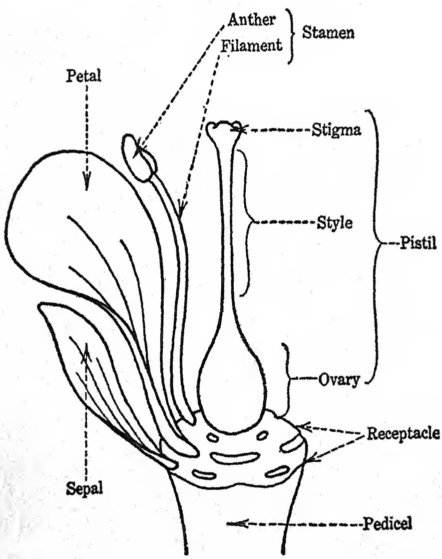

FIG. 74.—Diagram of a flower from which all but one of each whorl of flower parts have been removed. (Modified after Hall. From Holman and Robbins, in a Textbook of General Botany.)

Flowers are exceedingly various. There are flowers so small that their organs are scarcely visible to the unaided eye; such are the flowers of the duckweed or duckmeat (*Lemna*), which are free, floating plants common in ponds throughout the world. Then there are the flowers of a tropical plant (*Rafflesia*), growing on the floor of dark forests, which are as much as a yard in diameter. A great host of flowers like those of grasses, cotton-woods, and oaks are adapted to wind-pollination, whereas others, like those of orchids, snapdragons, and mints, are so peculiarly constructed that the pollen is distributed only by certain insects whose bodily form enables them to enter the flower. The flowers of grasses, cottonwoods, birches, and many other wind-pollinated plants have no showy bright-colored parts; insect-pollinated flowers, on the other hand,

are usually gaudy and conspicuous. We might go on enumerating the great number of variations in the size, color, structure, and form of flowers, but lack of space prohibits.

Let us now familiarize ourselves with the structure of some typical flower—one which has all parts present.

Exercise 85. The parts of a flower. Examine the flowers of some plant, such as cherry, sweet pea, radish, or lily. The following principal parts will be observed:

1. The sepals, green structures; taken together they form the **calyx**. The calyx covers the other flower parts in the bud.

2. The **petals**, showy, colored structures; taken together they form the **corolla**.

3. The **stamens**, slender structures, each with a thread-like **stalk** or **filament** at the end of which is an **anther**. The anther produces a yellow powder called **pollen**.

4. The **pistil**, the central structure of the flower. The parts of the pistil are the **ovary**, the swollen base which contains the **ovules**, that is, the structures which later develop into seeds; the **stigma**, the topmost part of the pistil which steals the pollen from insects or wind or other agency which transports it; and the **style**, the slender part of the pistil which connects the stigma with the ovary.

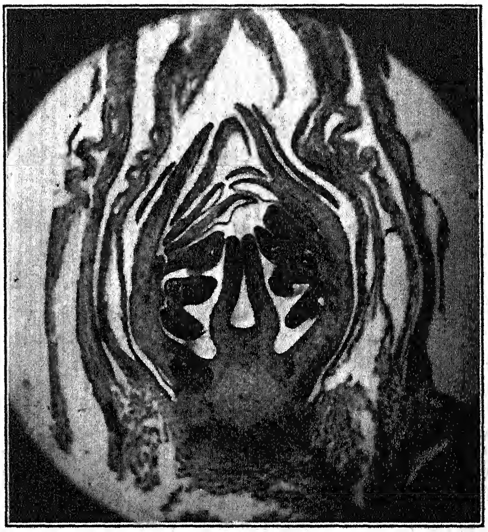

FIG. 75.—A lengthwise section of an apricot flower bud, long before it is ready to open. Observe the immature ovary in the center, the stamens, the petals and sepals, and the overlapping bud scales. (Photograph furnished by Division of Pomology, California College of Agriculture.)

Within recent years scientists have found that all flowering plants bear microscopic sexual plants as parasites in their flowers. Just so is the human embryo a parasite upon its mother. The yellow pollen grains are nothing more or less than male plants;

and hidden within the young seeds (ovules) are the parasitic female plants. The germ cells, that is, the eggs and sperms, are not produced directly by the flowers. Instead, flowers develop these small sexual plants which in turn bear the eggs and sperms. Within each anther there are developed a number of **spores**, a peculiar type of cell which, unlike eggs and sperms, is capable of growing into a plant without entering into the mysterious process of fertilization. Each of the spores in the anther grows into a minute male plant, a pollen grain. When the anther dries up and splits open, powdery masses of yellow male plants are carried by insects or wind to the pistils, inside of which the female plants are waiting.

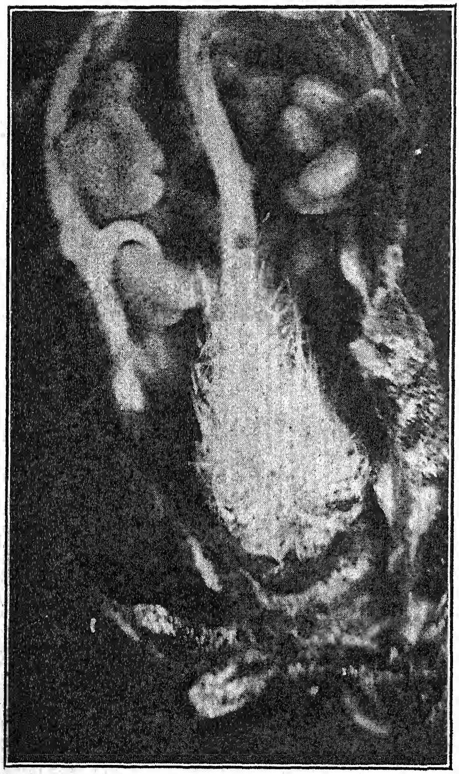

FIG. 76.—An apricot flower bud just before opening. The ovary, covered with hair, is seen in the center, and above are the anthers. (Photograph furnished by Division of Pomology, California College of Agriculture.)

Exercise 86. The pollen grain. With the compound microscope examine the pollen grains of some flowering plant. In specially stained pollen grains will be seen the protective coat enclosing two cells. The nuclei of these cells are visible. Thus, it is seen that the pollen grain is not a single cell, but in reality a small sexual plant consisting of but two cells.

Exercise 87. Germination of pollen grains. The pollen grains of many plants will germinate in a 10 per cent solution of cane sugar. Prepare hanging

drop cultures of a number of different kinds of pollen in the above solution. Germination of the pollen grain, like that of the seed, is resumption of growth. Under favorable conditions the two-celled male plant (pollen grain) germinates, germination consisting of the growth of a long tube—the pollen tube. One of the cells divides to form two sperms or male elements. These may be seen in properly stained material, usually occupying a position near the end of the tube. In the mature pollen tube may thus be seen three nuclei, a so-called **tube-nucleus** and two **sperm nuclei.** These nuclei are accompanied by some cytoplasm.

The pistil is the young seed pod. Inside of each potential seed, which in the early stages is called the **ovule**, there is a single female plant. This is a minute, swollen bag and is called the **embryo sac.** At the end of the female plant or embryo sac, nearest an opening which is always left in the seed coats, there lies the cell which is to be fertilized. This is the **egg cell**, the female element. Such a cell, wherever found, whose sole function is union with a male cell, is called an **egg.**

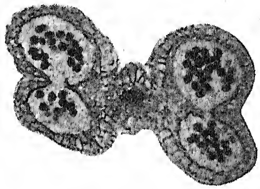

FIG. 77.—Cross-section of a mature anther showing the four pollen chambers containing pollen grains.

Exercise 88. Structure of the ovule. Split open the pistil of a flower and observe the one or more ovules. The internal structure of these can be studied only by appropriate microscopic sections. The central part of the ovule consists of a mass of tissue called the **nucellus.** Embedded within it is the **embryo sac,** the female plant. Entirely surrounding the nucellus, excepting for one small opening, **the micropyle,** is a protective layer, consisting of one or two coats, the **seed coats.** Within the embryo sac are a number of cells, one of which, the **egg cell,** after union with a sperm from the pollen grain, grows into a new plant.

Fertilization. When the embryo sac or female plant in the ovule is mature, the stigma is usually moist and somewhat sticky and conditions upon its surface are such as to cause the young male plant, the pollen grain, to resume its growth. In its growth it becomes, as we have seen, a microscopic, hair-like tube, the **pollen tube.** This tube grows down inside the pistil, through the micropyle, and into the female plant. The end of the tube bursts, emptying into the female plant the two sperm cells of the male. A sperm slowly dissolves itself in the egg. The two become one. This union of a cell from the male plant with a cell from the female

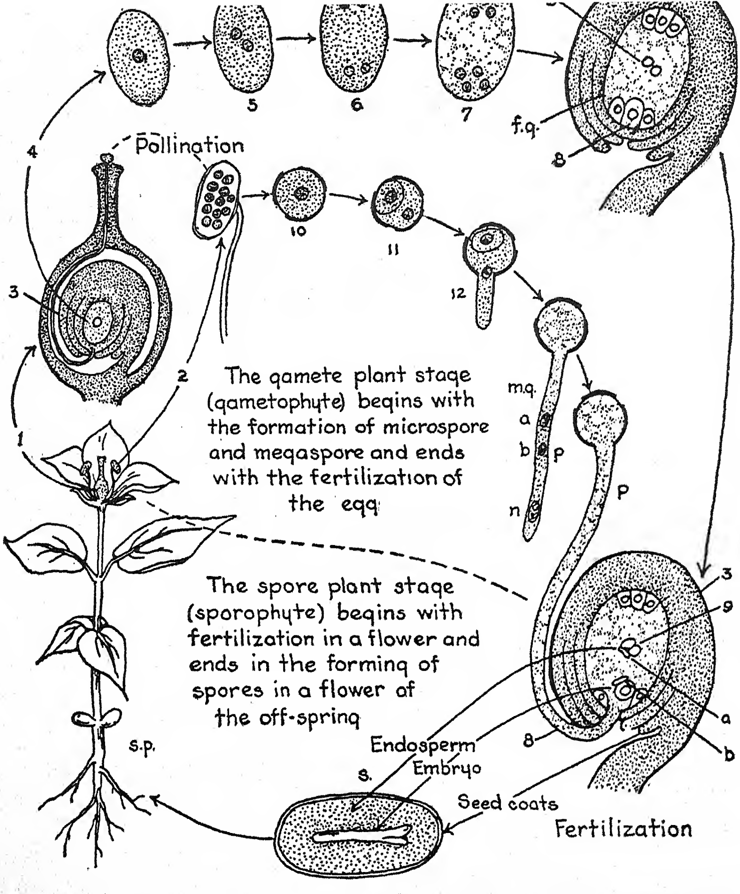

FIG. 78.—Life cycle of a seed plant with an enclosed ovule (Angiosperm). The seed (s) germinates and develops into the mature spore plant (s.p.). In the flower of the plant the sex organs, pistil (1) and the stamens (2) appear. The flower produces two different kinds of asexual spores. Within the ovule (3) the megaspore (4) develops. This megaspore germinates and goes through the stages, 5, 6, 7, in developing into the female gamete plant (f.g.) which produces an egg (8) and a fusion nucleus (9). The pollen grains germinate and develop (11, 12) into the male gamete plant (m.g.) with a pollen tube (p) containing a tube nucleus (n) and two sperm cells (a, b). In developing, the pollen tube grows down through the style of the pistil and around the ovule to the micropyle where it enters the ovule. The end of the pollen tube enters the female gamete plant where its wall dissolves, setting free the cells, a and b. The union of a male gamete with the fusion nucleus results in the development of the endosperm (stored food) of the seed. The union of b with the egg (fertilization) results in the forming of the embryo spore plant in the seed. The seed coats result from the development of the outer coats (integument) of the ovule. The seed usually goes through a dormant period before germinating.

plant is **fertilization.** The process of fertilization, wherever it occurs in the plant and animal kingdoms, is really the same, in that it is the **union of two masses of living material, a sperm and an egg.**

The fertilized egg immediately divides and redivides. Soon, it changes from a shapeless mass to one showing the beginnings of leaves, stem, and root. Then the seed coats harden and the embryonic plant ceases to grow, awaiting favorable conditions for resuming growth. The whole structure has now become a **seed.** Its essential structure is the **embryo**—the result of fertilization of an egg by a sperm. The embryo is a new plant, borne for a while by the mother plant. Inasmuch as one mother plant may produce thousands of seeds, there is a great multiplication of individuals. This is reproduction.

Parthenogenesis. Normally, as stated, the egg or female gamete will not start on the train of changes which result in the embryo plant unless a sperm or male gamete fuses with it. Rarely, however, the embryo develops from an unfertilized egg nucleus. This phenomenon is called **parthenogenesis.** It is a rare occurrence among plants. The phenomenon has been observed in the dandelion, in hawkweeds, meadow rue, and several other groups of flowering plants. Also it has been observed in certain of the lower plants, chiefly fungi.

Parthenocarpy. As a general rule, lack of fertilization of the ovules is

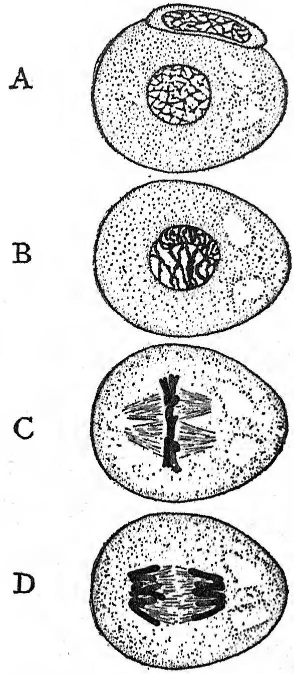

FIG. 79.—The earliest stages in the life of a plant. This shows how a plant starts out in life. The sperm nucleus moves into position beside the egg nucleus, as shown in A and B. The two divide side by side as shown in C and D so that there are two resulting groups of six chromosomes, instead of four groups of three. Each of the two groups then forms a single nucleus, and a cell wall forms between them. (From Robbins and Pearson, in Sex in the Plant World.)

followed by the shedding of the blossoms; the fruit fails to develop completely if a good number of the ovules are not fertilized. However, development of the ovary does sometimes occur although fertilization fails. Such an unusual development is called **parthenocarpy.** With certain sorts of both apples and pears, fruits have been developed without fertilization. Of course, parthenocarpic fruit is seedless. There are among cultivated plants many which bear seedless fruit. Seedless tomatoes, egg-

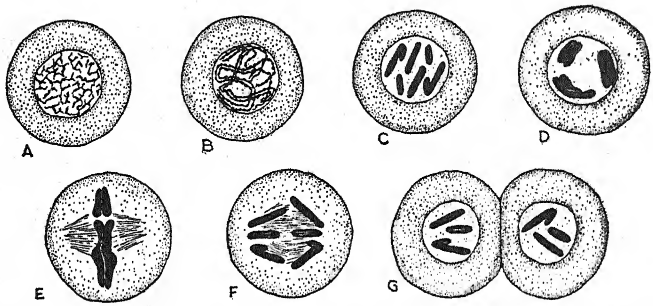

FIG. 80.—The peculiar cell divisions by which eggs and sperms are formed. (Redrawn from Robbins and Pearson in Sex in the Plant World.)

plants, English forcing cucumbers, oranges, grapes, and bananas are quite common examples.

Problem 2. How is pollen dispersed?

We have learned that the pollen grain, when shed by the anther, usually consists of a two-celled male plant, enclosed by a thick, protective wall. The pollen grains of flowering plants differ greatly in size, shape, and surface markings. Inasmuch as plant pollens are responsible for much of the hay fever, there has been much interest in them, and some investigators have become proficient in identifying them under the microscope.

Exercise 89. Different kinds of pollen grains. Examine, under the compound microscope, pollen from a variety of plants, including such common hay-fever plants as ragweeds, Russian thistle, pigweeds, grasses, oak, black walnut, poplars, and elms. Also observe the winged pollen grains of pine. For

examination of pollen grains, mount them dry on a slide, or in a mineral oil and cover with a glass slip. When mounted in a watery and most other liquid media, the grains either shrink or swell, or become distorted.

Quantity of pollen. The amount of pollen given off by plants is enormous. One worker counted 243,000 pollen grains, the output of a single dandelion blossom. This same worker estimated that an entire rhododendron plant produced approximately

FIG. 80.—The pollen-bearing catkins of walnut. The catkins are easily swayed by the wind, and the pollen is light in weight and produced in abundance. These characters make the plant well adapted to wind pollination. (Photograph furnished by Division of Pomology, California College of Agriculture.)

FIG. 82.—The cleistogamous flowers of closed gentian. The flowers never open; hence only self pollination can occur.

72,620,000 pollen grains. It is said that a medium-sized Indian corn plant will produce as many as 50,000,000 pollen grains. Gager says: "It was calculated that between 8 A.M. and 1 P.M. on a certain day there were given off from a single plant of *Ambrosia trifida* (ragweed) the amazing number of eight thousand million (8,000,000,000) pollen grains."

Agents which disperse pollen. Pollen is carried chiefly by wind and insects. Even when male and female organs are borne

in the same flower, as they usually are, outside agencies are most always depended upon for pollen transportation. In fact, there are only about 150 species of flowering plants which do not need pollinating agents. These are the cleistogamous flowers (from cleisto-closed + gamos-marriage). Their flowers never open, and their pollen tubes grow directly from the stamens into the pistils. Certain violets are an example of such flowers.

Such inconspicuous flowers as those of grasses, cottonwoods, alders, birches, oaks, hickories, and pines are notable among those which have their pollen dispersed by the wind. With the exception of the nut fruits, the common tree fruits are largely dependent upon insects for the dispersal of their pollen.

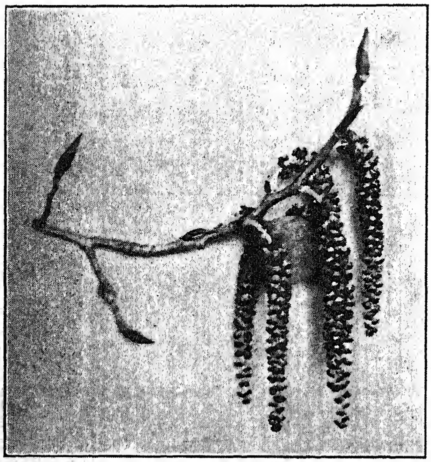

FIG. 83.—Staminate flowers of cottonwood. Wind carries the pollen from the cottonwood tree bearing staminate flowers to the pistils of the tree bearing pistillate flowers.

In grasses the flowers are inconspicuous, they lack odor and nectar, and hence are unattractive to insects; furthermore, the pollen is light and dry, and easily blown; the stigmas are feathery and expose a large surface to flying pollen; and pollen is often produced in great quantities. For example, in corn, it is estimated that each staminate flower group (tassel) produces 20,000,000 to 50,000,000 grains of pollen. There are in the neighborhood of 45,000 pollen grains produced for each ovule. The styles, the corn "silks," are long and plumose, and are receptive throughout their entire length. Pollen grains of wind-pollinated flowers are often much roughened. What is the advantage of this to the plant?

In cottonwoods, alders, birches, oaks, and hickories, the flowers are in catkins. The staminate catkins are pendulous and move

easily in the wind, and the light pollen is shaken from the anthers and readily carried away by the breezes. In many catkin-bearing trees the flowers open before the leaves unfold so that pollen movement is unhampered.

In pines, the flowers are also borne in short catkins; and, in addition to this feature which favors wind dispersal of pollen, the pollen grains themselves are provided with two wings which assist in their distribution by the wind. In pines, pollen is produced in tremendous quantities. At the proper season, showers of pollen may be witnessed in the pine forest; one's clothing may become yellow with the pollen grains.

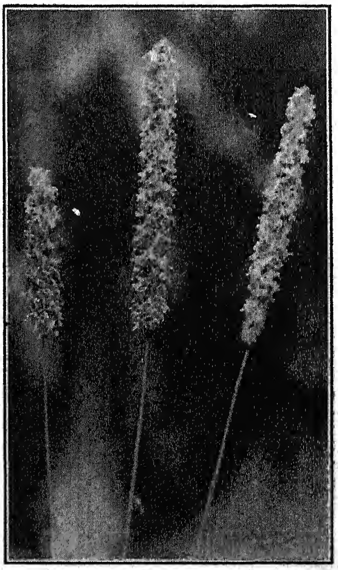

FIG. 84.—Timothy in bloom. The grasses have flowers that are not showy or fragrant. They are fitted by structure and position to wind-pollination.

The principal pollinating insects are bees, the most efficient of which are the honeybee and the bumblebee. It is known that French and sugar prunes in California and Napoleon and black Tartarian cherries set a very light crop unless a large number of bees are present in the orchards at the time of blooming. In fact, insects are necessary for the pollination of most deciduous fruit trees except certain nuts.

The flowers of red clover must be cross-pollinated in order to set seed on a commercial basis, and the bumblebee is chiefly responsible for carrying the pollen. This insect is capable of pollinating 30 to 35 clover flowers a minute. Have you noticed that bees in their work confine themselves, for the most part, to visitation of the flowers of one species? What is the advantage of this to the plant?

In many types of figs, including Smyrnas, but excepting the common black fig, all or at least one of the crops require the visi-

tation of the fig wasp, bringing with it pollen, for the fruit to form properly.

The moths and butterflies are also important pollinating agents. They are particularly adapted with their long mouth-parts to securing nectar from flowers with long tube-shaped corollas, such as larkspurs, columbine, and nasturtium.

Insects are attracted to flowers chiefly by their odor and color. Odor appears to be the more important influence. Many flowers

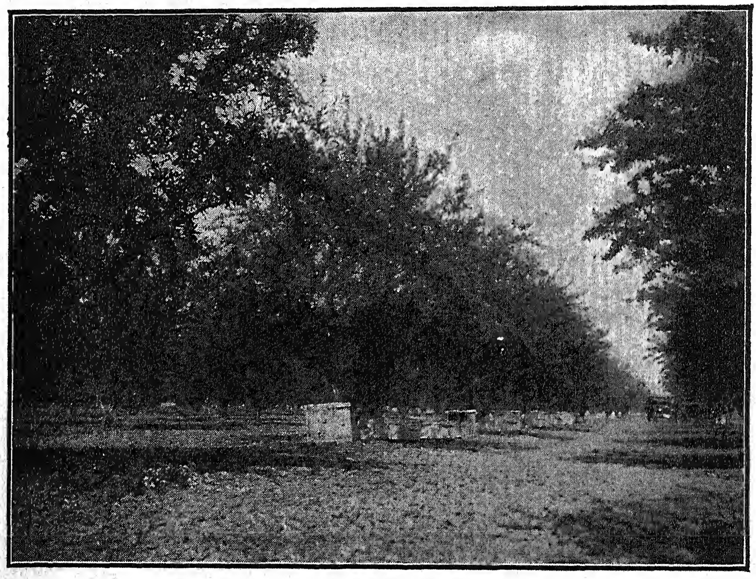

FIG. 85.—Hives of honey bees in an orchard. The insects carry pollen from flower to flower, thus bringing about a better setting of fruit. (From Division of Pomology, College of Agriculture, University of California.)

have special nectar-secreting structures known as **nectaries** or **nectar glands**. Sugar is the main secretion of these glands. Insects also visit flowers in search of pollen, which is used as a food mainly for the larvae.

In general, insect-pollinated flowers have both stamens and pistils in the same flower; the stamens usually have short filaments, the flower groups are quite inflexible, the pollen is often

sticky and produced in relatively small quantities, and the flowers are attractive because of their showiness or odor.

Enumerate the features which are favorable to insect pollination. To wind pollination.

Compare insect- and wind-pollinated plants as to waste of pollen.

How do you account for the fact that house plants often set less seed than plants growing out-of-doors?

Longevity and viability of pollen. Pollen varies considerably in the length of time it will remain viable (capable of germination), depending upon the moisture and temperature conditions surrounding the grains, and upon the kind of pollen.

Corn pollen does not remain viable much longer than 24 hours after shedding. That of *Hibiscus trionum* lives no longer than 3 days. Pollen of the date palm will retain its viability for several months, if kept dry. The longevity of apple pollen has been variously reported by different investigators. One worker records germinations of 12, 10, 5, and 8 per cents for different lots after 7 months of storage in the laboratory, with a temperature ranging from 50° to 65° F. The pollen of apple and plum remains alive much longer if stored in closed vessels which prevent drying out than when stored in the open. The pollen of some plants, such as sugar beet, alfalfa, and red clover, absorb water rapidly and burst in water or in a saturated atmosphere. Such pollen loses its viability rapidly in an atmosphere of high relative humidity.

Dry pollen will withstand greater temperature extremes than moist pollen. However, resistance to low temperature is also a specific character. For example, pollen of apple, pear, and plum will withstand temperatures ranging from 33° to 34° F., whereas about 50 per cent of peach and apricot pollen grains are killed by this temperature.

Immediate effect of pollen. It is noticed that shortly after pollination the stigma withers. This is the immediate effect of pollination. After a time the petals also wither and drop off. If flowers are bagged and pollination prevented, the petals remain fresh for a much longer time than they do in pollinated flowers.

Problem 3. What are the important different types of flowers?

In Exercise 85 we learned the principal parts of a typical flower. These are as follows: the **sepals**, the **petals**, the **stamens**, the **pistil**. Such a flower is said to be a **complete flower**. But not all flowers have these four sets of floral organs; one or more of

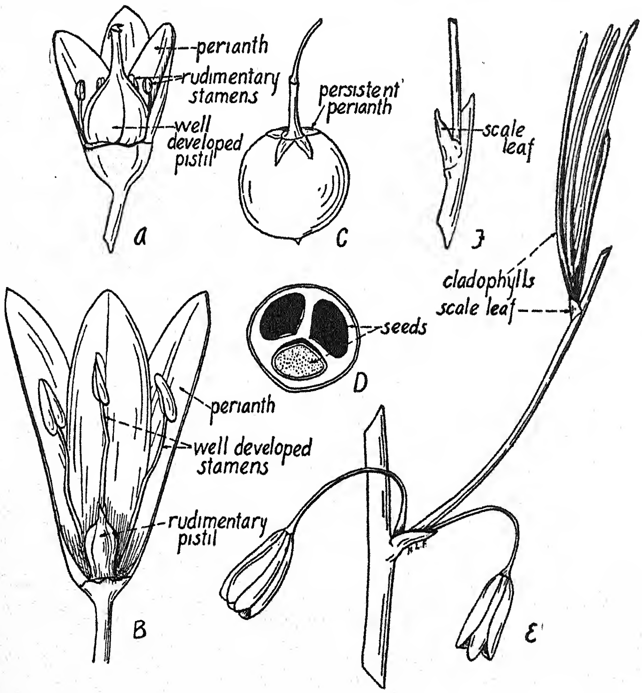

FIG. 86.—Garden asparagus (Asparagus officinalis). A, pistillate flower; B, staminate flower; C, mature fruit; D, section of fruit; E and F, portions of the plant showing method of branching, position of flowers and leaves. (From Robbins, in Botany of Crop Plants.)

these sets may be lacking, in which case the flower is said to be **incomplete**.

Incomplete flowers. In the buckwheat flower, for example, the petals are absent. In the flowers of willows and cottonwoods, both sepals and petals are lacking. In both of the foregoing cases

the essential organs (stamens and pistil) are present. However, some flowers have but one set of essential organs, either stamens or a pistil. A flower with stamens only, and no pistil, is said to be **staminate** (male). On the other hand, a flower with a pistil but no stamens is said to be **pistillate** (female). Staminate plants do not bear fruit and seed; only pistillate plants perform this function. Staminate and pistillate flowers may be on the same individual plant; this is true of corn, in which the "tassel" is a group of staminate flowers and the "ear" a group of pistillate flowers. The squashes, pumpkins, and melons are other examples of plants which bear staminate and pistillate flowers on the same plant. Or staminate and pistillate flowers may be on different individual plants; examples of such plants are asparagus, spinach, hops, willows, and date palm. In these plants the flowers on any one plant are either all staminate or all pistillate. Thus we may speak of staminate (male) plants and pistillate (female) plants.

In certain cultivated species which have male and female individuals, one of the two kinds of plants may be more desirable from the grower's standpoint than the other. For example, in the date palm it is desirable that most of the individuals be pistillate since these alone can bear the edible fruit. In the hop plant, it is only from the pistillate plants that the "hops" are obtained. In asparagus, it has been found that the yield of edible spears from staminate plants exceeds that from pistillate. Staminate cottonwoods are preferred to pistillate ones because of the "litter" caused by the cotton-covered seeds.

Exercise 90. Incomplete flowers. Study the incomplete flowers of such plants as pumpkin, spinach, asparagus, willow, cottonwood, and begonia. What is a staminate flower? A pistillate? Why are staminate cottonwood trees better as street trees than pistillate ones? How can you propagate staminate individuals? Will a solitary asparagus plant produce fruit? A solitary cottonwood? A solitary hop-vine? Explain why.

Lily type of flower. The lily family includes such well-known plants as the lily, yucca, hyacinth, tulip, onion, and asparagus. In this family, the parts of the flowers are in threes. The non-essential organs consist of six separate parts, in two circles of three each, which are generally very similar in size, shape, and color. The anthers are usually large and conspicuous. The ovary is

FIG. 87.—Lilium grandiflorum, a monocotyledon.

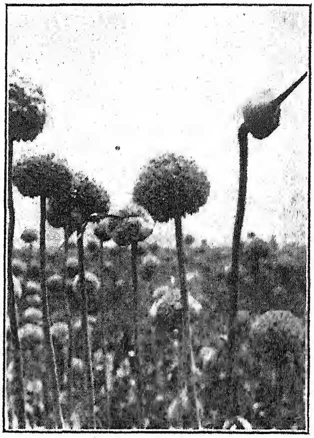

FIG. 88.—The inflorescence (umbel) of leek, a plant closely related to onion. At the top and right is a flower-group still enclosed.

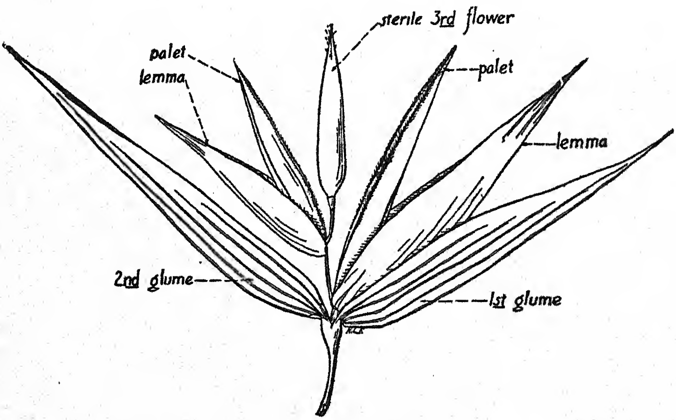

FIG. 89.—Spikelet of common panicle oats, ×2½. (From Robbins, in Botany of Crop Plants.)

divided into three chambers, each of which commonly has several seeds. Flowers of the lily type are chiefly insect-pollinated. Name ten plants of economic importance belonging to the lily family.

Grass type of flower. The flower of the grass family (*Gramineae*) is peculiar. It may be studied to advantage in such common grasses as wheat, oats, barley, and rye. In all grasses, the flowers are in groups, each group being called a **spikelet**. A typical spikelet, such as that of oats or wheat, consists of a short axis, bearing a number of chaff-like bracts. The two lowermost bracts, called **glumes**, are empty, that is, do not bear flowers in their axils. Above the two glumes are one or more bracts called **lemmas**, and usually there is a flower in the axil of each. Each flower consists of three stamens and a single pistil. The ovary contains a single ovule and has two feathery stigmas. The awns or beards of a grass are brittle structures usually attached to the lemmas. Do you think that inconspicuous flowers of the grass type, with their lack of showy parts and nectar glands, are wind-pollinated or insect-pollinated? Explain.

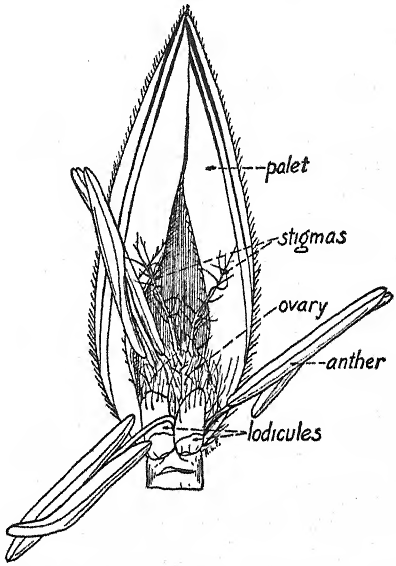

FIG. 90.—Wheat flower with lemma removed; considerably magnified. (From Robbins, in Botany of Crop Plants.)

Exercise 91. Dissect the spikelets of oats, wheat, or barley, and find the parts described in the previous paragraph. Write a short paper on the topic "Grasses and Man."

Mustard type of flower. The mustard family (*Cruciferae*) includes a number of familiar plants such as cabbage, turnip,

rutabaga, rape, mustard, radish, watercress, and horseradish, and a number of pernicious weeds such as pennycress, wild mustard or charlock, shepherd's purse, false flax, and tansy mustard. The mustard flower is characteristic. It has four sepals, four petals, six stamens (two short and four long), and a two-celled ovary. The four petals are so arranged that when one looks at the face of the flower it has the appearance of a Greek cross, hence the name *Cruciferae* (Latin, *crux*, cross, + *fero* bear). The pistil has a single style with a more or less two-lobed stigma. Insects are the principal agents in the pollination of mustard flowers. Why? Name ten plants of economic importance belonging to this family.

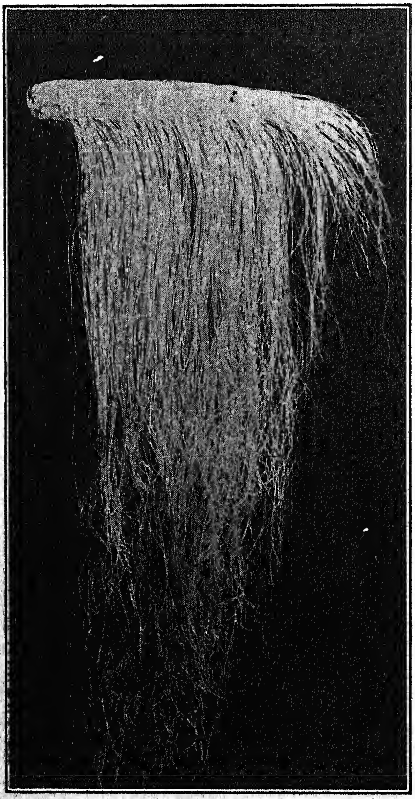

FIG. 91.—Corn (Zea mays). Young pistillate inflorescence ("ear"), showing the long styles ("silks"). (From Robbins, in Botany of Crop Plants.)

Rose type of flower. The family *Rosaceae* includes such plants as the raspberry, blackberry, dewberry, strawberry, spiraea, and rose. The flowers are generally complete, except in some cultivated varieties of strawberries. There are usually five sepals and five petals. In most cultivated roses, which have double flowers, there are numerous petals which have developed from young tissue that normally becomes stamens. Except in these double sorts there are numerous stamens, and as a rule, a number

of separate pistils. The rose type of flower is chiefly insect-pollinated.

Apple type of flower. The apple, pear, quince, loquat, and service berry are members of the apple family (*Pomaceae*). This family bears flowers which are complete and usually have a concave or cup-shaped receptacle, to which are attached a five-lobed or five-toothed calyx, five separate petals, numerous distinct stamens, and a one- to five-celled ovary. Pollination of the apple type of flower is brought about by insects.

Plum type of flower. The plum family (*Drupaceae*) includes the plum, cherry, almond, peach, and apricot. This is a group commonly known as the stone fruits. The flowers are complete. The corolla and calyx each have five distinct parts. There are numerous stamens. In a longitudinal section of the drupaceous flower it is seen that the ovary is placed down within a cup commonly called the "calyx tube." There is one pistil situated at bottom of the hollow receptacle, and a one-celled ovary, usually maturing one seed. Pollination of the plum type of flower is chiefly by insects.

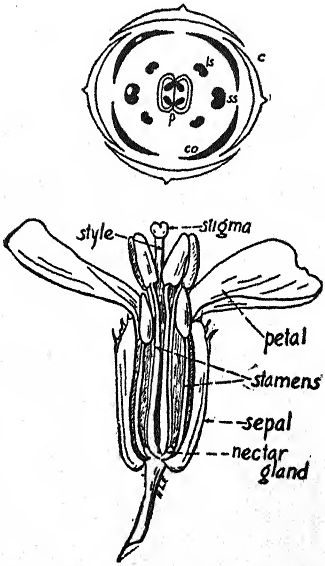

FIG. 92.—Flower of mustard. Diagram of flower above, and flower in median lengthwise section below. (From Robbins, in Botany of Crop Plants.)

Legume type of flower. The pea family (*Leguminosae*) is one of wide geographical distribution and possesses a great many species. Well-known representatives are common garden pea, vetch, sweet pea, clovers, sweet clovers, alfalfa, bean, cow-pea, soy bean, and peanut. The flowers are irregular in form; they have a butterfly-like shape. The calyx is usually four- or five-toothed. The petals are normally five in number, a broad upper one (**standard**), two side ones (**wings**), and two lower ones more or less

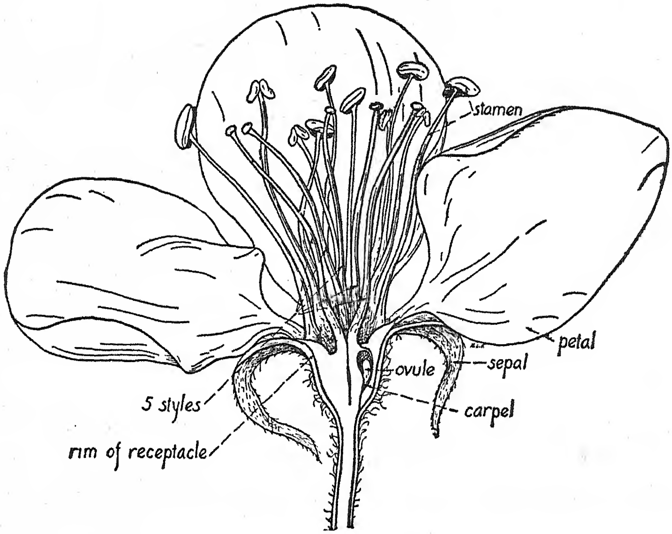

FIG. 93.—Median longitudinal section of apple flower. (From Robbins, in Botany of Crop Plants.)

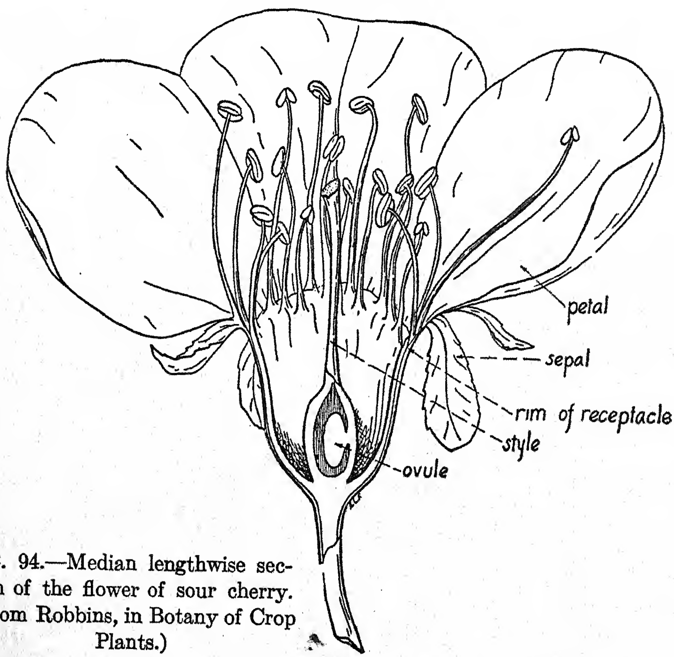

FIG. 94.—Median lengthwise section of the flower of sour cherry. (From Robbins, in Botany of Crop Plants.)

united along one edge, forming the **keel**; this keel incloses the stamens and pistil. Stamens are usually ten in number; commonly nine are united and one is free. There is a single pistil, with one cell. Some of the legumes, such as the garden pea, are self-pollinated; many others are pollinated by insects.

Composite type of flower. The thistle or composite family (*Compositae*) possesses a number of well-known plants, among which are common lettuce, Jerusalem artichoke, endive, salsify, dandelion, yarrow, sage, chrysanthemum, sunflower, golden rod,

FIG. 95.—The choke cherry has its flowers in long racemes.

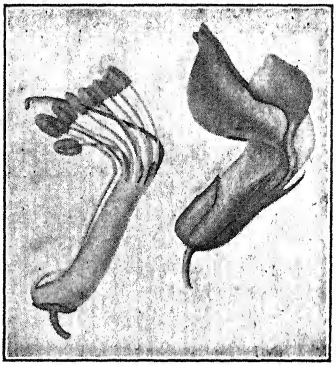

FIG. 96.—Flower structures of the pea or legume family. Left, the calyx and corolla have been removed, exposing the stamens (10) and the style. Nine filaments are united at base to form a tube which surrounds the ovary; 1 stamen is free.

sow thistle, dahlia, aster, marigold, fleabane, everlasting, Spanish needles, and thistle. In this family the individual flowers are grouped to form a flowerhead. A " sunflower " is not a single flower, but a group of individual flowers, mounted on a common receptacle. As a rule, in the flower head, there are two kinds of flowers: (1) those about the margin, called **ray flowers**; and (2) those in the center, known as **disk flowers.** In such composites as lettuce, however, all the flowers of a head are alike. The disk

flowers have a calyx made up of bristles or scales. These are attached at the top of the ovary. The corolla is tube-like, and on its side are attached the five stamens. There is a single pistil, which has a one-seeded ovary, and a single style. The ray

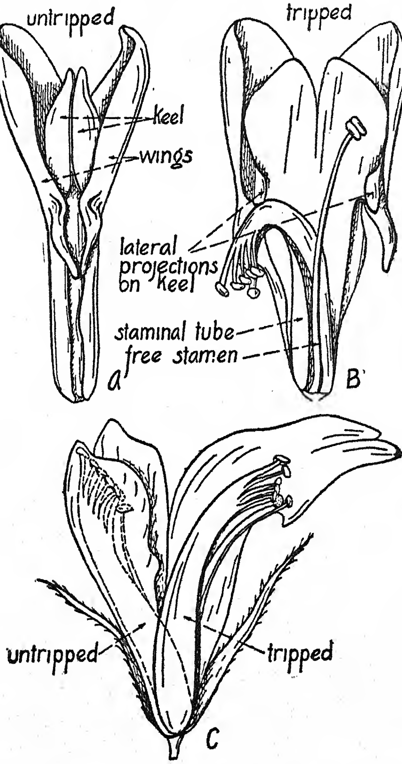

FIG. 97.—Pollination of alfalfa. A, flower untripped with calyx and standard removed; B, same tripped; C, position of staminal tube untripped and tripped. (After U. S. Dept. Agr. from Robbins, in Botany of Crop Plants.)

flowers are usually imperfect. Insects are the principal agents in the pollination of composite flowers.

Double flowers. Many cultivated plants tend to develop double flowers. Well-known examples are forms of dahlias, chrysanthemums, pinks, roses, and hollyhocks. Doubling may arise

through the change of stamens or pistils to petals, or through the origin of extra petals in the circle of petals.

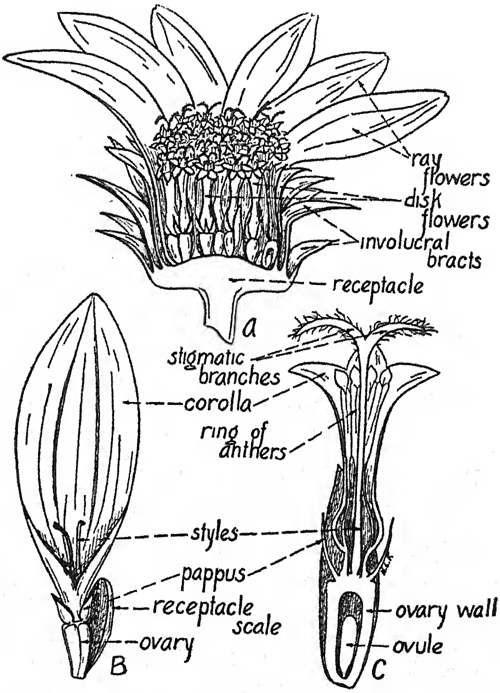

FIG. 98.—Jerusalem artichoke, a member of the composite family. A, lengthwise section of the flowering head, ×I; B, ray flower, ×6; C, disk flower, cut lengthwise, ×6. (From Robbins, in Botany of Crop Plants. A after Baillon.)

Exercise 92. A study of flower types. Study the following types of flowers: mustard, rose, apple, plum, legume, composite, and double. These should be dissected. Prove to your own satisfaction that each of the flowers studied illustrates the features of the type to which it belongs.

Problem 4. What are the principal causes of the failure of blossoms to set fruit?

There are often reproductive failures in plants. They may bear an abundance of blossoms, but owing to one or more causes,

fail to set fruit. Among these causes may be mentioned the following:

1. Pollen is not shed at the time when the stigmas are receptive. The pollen may be shed before, or after, the stigmas are receptive. In some American plums, particularly during periods of cold weather, the stigma may pass the receptive condition before the pollen is mature. What visible evidence is there that a stigma is ready to recieve pollen?

2. Pollen is not viable. Some cultivated varieties of grapes bear impotent pollen. Certain varieties of strawberries (Glen Mary and Crescent) produce impotent pollen and hence are self-sterile. Several commercial varieties of peaches, notably Chinese Cling and J. H. Hale, produce no good pollen. They are male sterile. Of course, these varieties will not set fruit unless interplanted with varieties which will furnish pollen.

3. Imperfect flowers. There is a commercial sterility problem with strawberries involving chiefly the impotence of the pistils of the perfect flowers. Certain varieties of strawberries develop only perfect flowers, and all flowers are fertile. Other varieties have more or less female sterile perfect flowers, and still others bear only pistillate flowers. If such a variety as the last mentioned is planted by itself, there will be no pollen. In planting varieties with pistillate flowers only, it is necessary to have rows nearby planted to pollen-bearing individuals.

4. Self-sterility. Many varieties of orchard fruits are not capable of setting fruit unless pollen from another variety is used. That is, they are self-sterile. For example, the Montmorency cherry is self-sterile but may be cross-pollinated by Early Richmond or English Morello. In some localities the Spitzenburg apple is self-sterile, but can be fertilized with pollen from a number of other varieties, such as Yellow Newton, Arkansas Black, Jonathan, and Baldwin. Evidently, the mutual affinities of varieties must be considered in setting out an orchard. It would not be well to plant solid blocks of Spitzenburg apple, for example. There should be, here and there in the orchard, trees of some one of the other varieties, the pollen of which is capable of fertilizing it.

Self-sterility in pears is the reason for the barrenness of many pear orchards. It has been frequently observed in many parts of

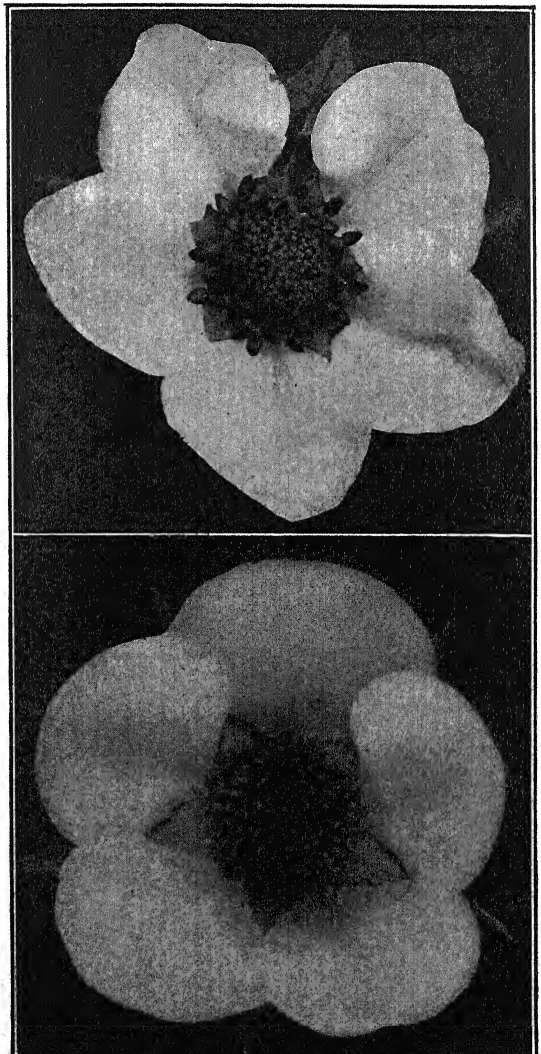

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FIG. 99.—Certain varieties of strawberry bear only hermaphroditic flowers (above). Other varieties of strawberry bear only pistillate flowers (below). (After Darrow, from Robbins and Pearson, in Sex in the Plant World.)

the country that when a certain variety of pear is planted in a solid block, a pronounced failure to set fruit often results. This is particularly true, it seems, of Bartlett and Kieffer pears. These varieties give much better results when they are planted with such varieties as Lawrence, Duchess, and Anjou.

5. Excessive production of flowers. Many plants initiate development of far more flowers than they can perfect; and often plants cannot mature all the fruits that set from those flowers which are perfected. The "June drop" of the immature fruits of certain fruit trees is due to the abortion of embryos which the trees have not reserve food enough to mature.

6. Unfavorable weather conditions. Fruit-setting may sometimes fail because of frost or because of cold, rainy weather which interferes with the movement of insects or delays the growth of the pollen tube; or hard rains which come immediately after the pollen is brought to the stigma may wash the grains from the stigmas. In the case of corn, hot dry winds may wither the "silks," making it impossible for the pollen to stick to them and germinate; as a result there is an incomplete "filling" of ears. What are the "silks" of corn? The tassels? Is corn wind- or insect-pollinated?

7. Lack of pollinating insects. In most of our orchard trees the pollen is carried by insects, chiefly bees. It has been shown that under certain conditions the percentage of flowers setting fruit can be increased by placing beehives in the orchard. It is usually considered that one hive of bees to one or two acres of orchard is sufficient.

There are other types of sterility among flowering plants. Abortion is a rather common occurrence in the plant kingdom. For example, in the coconut normally there are three sections in the ovary, but, while it is maturing, two of the sections abort; likewise in the date palm, which also has three sections in the ovary, only one section becomes a fruit; in oaks there are three sections in the ovary, each with two ovules, but the mature acorn has but one seed; in plums, cherries, almonds, and other stone fruits, the ovary normally has two ovules, but only rarely do both of these develop into seeds. In fact, when two seeds are found in a cherry it is occasion for special remark.

Several cultivated plants develop but a small number of flowers or only poorly developed ones. For example, some Irish potato varieties produce very few flowers; the same is true of the sweet potato, in which seeds may be almost lacking. In France, garlic seldom flowers. Sugar cane is a notable example of a plant which seldom produces seeds. How is a plant like sugar cane propagated? What is the advantage of reproducing potatoes by means of tubers rather than seeds?

Problem 5. How do ferns and mosses reproduce?

Among ferns, as among seed plants, the sexual function is performed by minute, very peculiar sexual plants. But in ferns there is no embryo sac in an ovule of the ovary, no masses of yellow pollen to be carried about by bees or blown in clouds by the winds. There are, instead, flat green growths hidden under the forest moss and mold. The largest kinds of sexual plants in ferns are seldom half an inch across; the smallest of them grow to maturity and produce their eggs and sperms all within the protective coat of the single spore from which they grew.

Exercise 93. How do ferns produce spores? Ferns have no flowers or stamens or pistils. Look on the under side of almost any fern frond in late summer or autumn and notice there the small, regularly arranged brown warts. Each of these consists of a group of spore cases (**sporangia**), in many instances protected by a covering of thin tissue (the **indusium**). Each group of spore cases is called a **sorus** (plural, **sori**). Mount some of the spore cases in water, and examine with the compound microscope. The spore case or sporangium is watch-shaped, with a thick wall about one edge, thin side walls, and a stalk. Inside are the **spores**. Give important differences between a spore and a seed.

In moist, protected soil, the spores germinate, each growing into a miniature green plant of one sex or the other, or even into plants bearing the organs of both sexes. Most fern **sexual plants** are peculiar flat growth like bits of leaves, heart-shaped and about $\frac{1}{6}$ to $\frac{1}{3}$ inch across. The sexual plants of ferns are called **prothallia** (singular, **prothallium**).

Exercise 94. How do ferns produce sex cells or gametes? On the moist soil beneath ferns, look for the prothallia of ferns. An experienced greenhouseman will always be able to find them for you. Study them with the dissecting

microscope. Observe that they have root-like threads (rhizoids) fastening them to the soil. Examine prepared slides showing the sexual organs.

The male organs—the structures producing sperms—are among the rhizoids; the female organs—the structures producing eggs—are clustered near the notch of the heart-shaped plant. A male organ is a minute spherical mass of cells protruding below the under surface of the prothallium. The inside

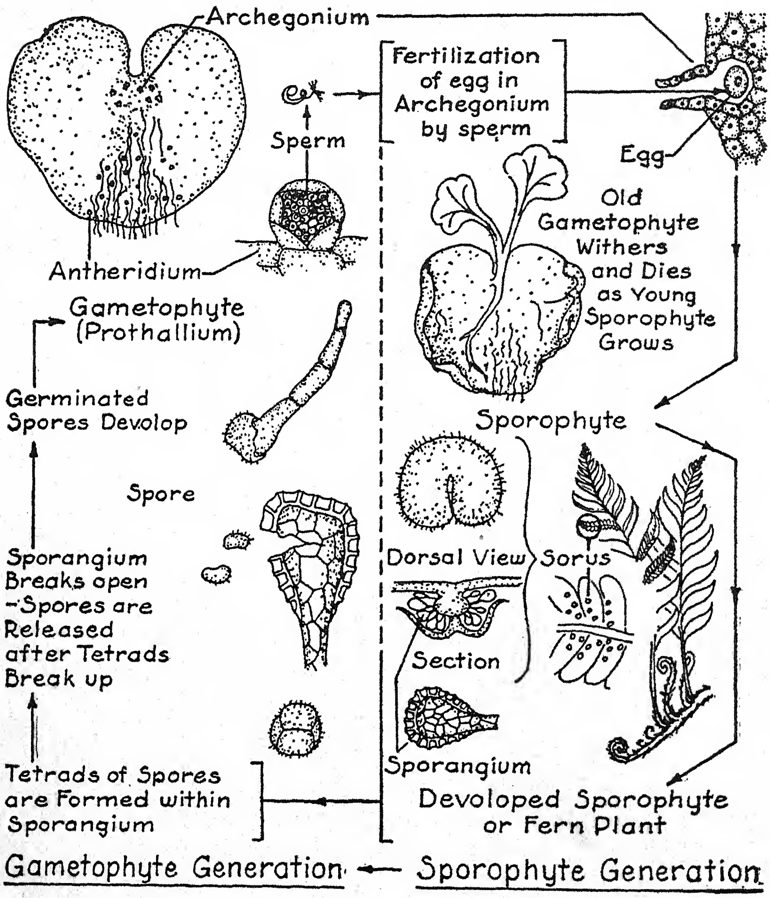

FIG. 100.—Life history of a fern. Note that the cycle is made up of a sporophyte generation which includes the showy fern plant, and a gametophyte generation which includes structures that are small and not frequently seen in nature.

cells of the male organ grow into long, coiled sperms, out of which curious long arms of protoplasm grow. With these arms, the sperms swim agitatedly about in the moisture under the prothallium until they reach the chimney-like structure of the female organs. A female organ is a flask-shaped structure,

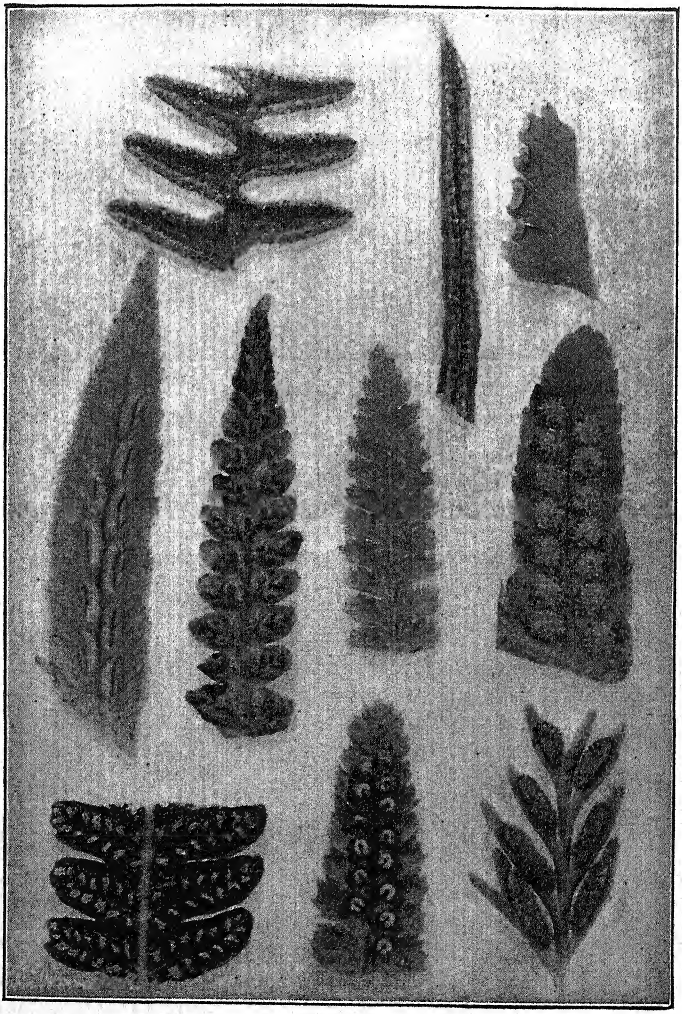

FIG. 101.—Fern fronds showing peculiar "warts" on the under sides. These are spore clusters. (From Robbins and Pearson, in Sex in the Plant World.)

the base of which is a chamber in which there is a single egg. The "neck" of the flask-shaped female organ is a chimney-like structure. The sperms swim

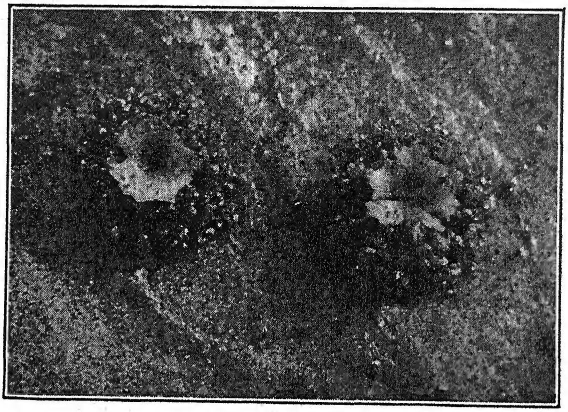

FIG. 102.—Two of the "warts" of Figure 101 highly magnified. These "warts" are essentially clusters of minute balls on stems. The balls are full of spores. (From Robbins and Pearson, in Sex in the Plant World.)

through these chimneys and fertilize the egg. Fertilized eggs grow out of the female plant, developing directly into the beautiful fern fronds we know.

FIG. 103.—Fern prothallia in the laboratory. Fern spores may be germinated in the laboratory if sown on damp inverted flower pots standing in a solution of small quantities of the salts required for their germination and growth.

Exercise 95. **What is the nature of the leafy moss plant?** Examine individual moss plants taken from a mossy turf. Each plant consists of a slender

stem or axis, bearing many tiny overlapping leaves. The plant is anchored to the soil by **rhizoids** which not only serve as holdfasts, but also absorb moisture. If moss leaves are mounted flat in water and examined with the compound microscope, it will be seen that they are very thin, often no more than one cell thick.

The asexual moss plant. The familiar mossy turf is the sexual generation of the moss plant; and instead of plants with leaves and stems and roots producing spores, like seed plants, the spore-producing moss plant has only a small brown capsule on a stalk growing directly out of the female sex organs and feeds as a parasite on the sexual plant. In the greenhouse or woods one can find these small capsule plants growing out of the mats of moss.

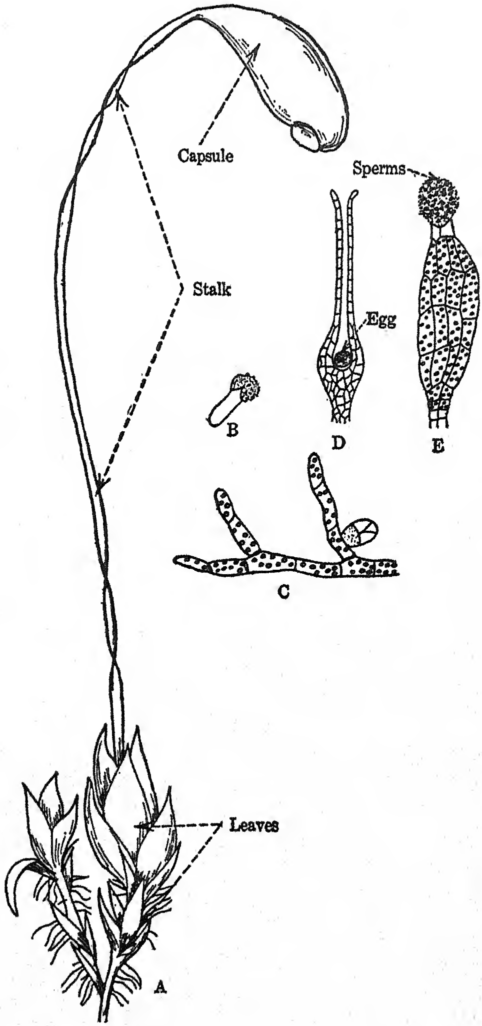

FIG. 104.—Moss. A, portion of leafy moss plant and spore-bearing structure; B, single spore showing germ tube; C, algal growth which develops from germinating spore; D, female sex organ; E, male sex organ. (From Holman and Robbins, in A Textbook of General Botany.)

Exercise 96. How do mosses produce spores? Study moss plants bearing the capsules (**sporangia**) each on a long stalk. The capsules or sporangia are

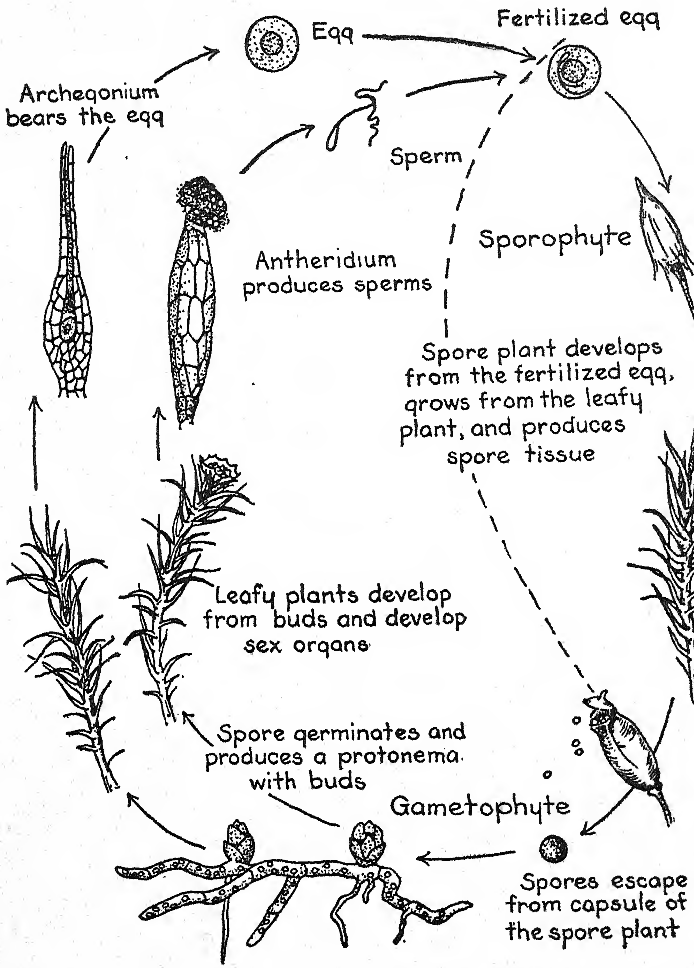

FIG. 105.—Life cycle of a moss plant, showing alternation of generations. Note that the spore plant results from the union of gametes and that the gamete plant results from the germination of a spore. How does the gametophyte of the moss get its food? What is the source of food of the sporophyte? Of what importance is chlorophyll in the life cycle of the moss plant? In what way is the gametic reproduction of moss different from the gametic reproduction of bread mold. What is the name given to the union of two unlike gametes resulting in the formation of a zygote?

nothing more than powder boxes of spores. Break open a mature capsule in a drop of water and examine the spores. When these spores germinate they develop into green moss plants. The early stages in the growth of moss plants from spores are green branching threads, growing close to the moist soil, and often giving to it a greenish color.

The sex organs of mosses look much like the sex organs of ferns. However, they are not embedded in the leafy sexual plant, and the male organs are larger and stalked and the female organs have longer necks. They are borne in clusters in the hearts of the buds at the tips of the moss branches. Their sperms can swim to the eggs in the slightest bit of moisture—perhaps a drop of dew.

Suggested activities. What is the importance of mosses in nature? Write a report on the importance of sphagnum and other mosses to man.

Problem 6. How do plants reproduce asexually?

The starfish, which is such a pest because it feeds on oysters, and the quackgrass, which chokes out crop plants and which the farmers of the country annually spend thousands of dollars to control, can not be killed by chopping up. Each dissevered arm of the starfish grows a whole new starfish; each stalk of quackgrass grows a whole new plant. Only a few simple animals can be multiplied by breaking them into pieces, but think of the many complex plants which can be reproduced in this asexual "vegetative" manner. Cuttings of stems of many roses, willows, apples, and a host of other plants will develop roots and grow if kept in moist soil. The strawberry sends out runners—stems with buds at the end—which root and form new strawberry plants in much the same fashion as the interesting "walking fern," except that in the fern it is the tip of a leaf from which the new plant grows. Begonia leaves will send out roots and stems and leaves if pinned closely to moist soil. Potato tubers and lily bulbs are also special asexual reproductive structures.

Exercise 97. The gemmae of liverworts. The liverworts, common in greenhouses and moist woods, are simple flat green growths, with distinct under and upper surfaces. Some kinds of them are much larger than most mosses and look like green snakeskin. They reproduce both sexually and asexually. Observe on the upper surface of certain plants minute cups full of very small green pieces of liverwort tissue no larger than the head of a pin;

these are called "gemmae." Currents of air scatter these on the moist soil and they grow directly into new liverwort plants. The plant has reproduced asexually.

Reproduction by fission. When a bacterium reproduces it splits across the middle into two bacteria. **Reproduction here is nothing more than cell division.** The cell in this case is a minute system which can grow and split into two systems, each capable of growing and splitting across the center into two more systems, and so on *ad infinitum.* This simple type of reproduction is called **fission.** It occurs among more complex one-celled organisms than bacteria.

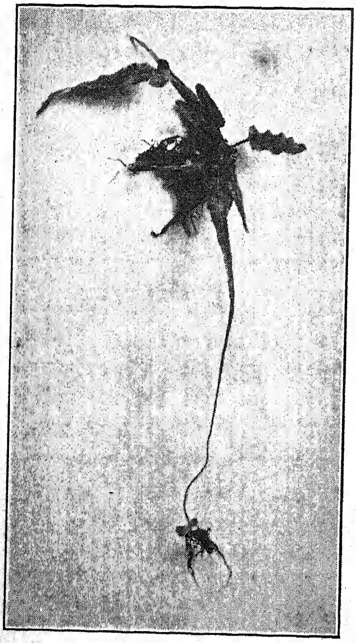

FIG. 106.—Walking fern showing vegetative reproduction, and migration of the plant.

The blue-green algae also reproduce by fission. Many kinds grow in hot springs, lining them with bright-colored crusts. Others grow in soil. Some are very troublesome in reservoirs, imparting a disagreeable flavor to the water. Also certain green algae reproduce by fission.

Exercise 98. Asexual reproduction in Protococcus. This is a one-celled plant which may be found growing on the north side of trees, on old damp boards, and on foundations of buildings. It forms a growth which resembles green paint. Scrape off some of the material with a knife and mount in water on a slide. Each cell is a separate plant. It will be observed that reproduction is accomplished by the division of the whole body of the parent.

Reproduction by spores. Everyone is familiar with the white threads of the "bread mold," which grows, as the name implies, on stale bread. The small black spherical bodies on stalks which it sometimes produces contain the asexual spores. These are in the

air, even in the best-regulated kitchen, and when in abundance produce the well-known musty odor.

Exercise 99. Asexual reproduction in bread mold. Moisten stale bread and place under a bell jar or other cover. Within a few days the surface of the bread will be covered with a cottony growth, and after a time there will appear numerous black bodies. These are spore cases or **sporangia.** Each sporangium contains thousands of spores. Examine with high-power dissecting microscope. Also mount spore cases in water, and study with the compound microscope. The significant feature of the asexual method of reproduction in bread mold is that the spores are capable of growing directly into new bread-

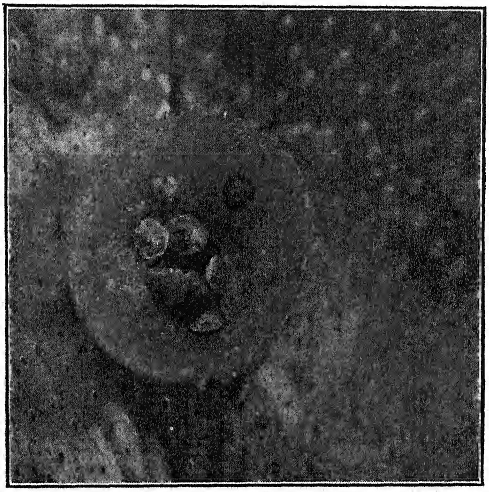

FIG. 107.—Cupfuls of tiny liverworts grow on the upper sides of old liverworts, odd relatives of the mosses. (From Robbins and Pearson, in Sex in the Plant World.)

mold plants. There is, however, sexual reproduction in bread mold, but the asexual method is by far the more important. (See pp. 101, 103.)

Slime molds are simple plants which creep about, streaming masses of slime, in rotting logs and stumps. Single slime-mold cells creep about and reproduce freely by fission. But besides fission these slimy masses have another method of asexual reproduction; this method is **spore formation.**

A spore is merely a living cell which seems to find it necessary

to escape from its mother that it may grow into a new plant. When slime molds initiate reproduction by spores, erect growths with solid walls appear on the slimy mass, and grow into small odd-shaped powder puffs of threads and heavy-walled spores. If these spores eventually settle in a sufficiently moist place, they open and release more spores. This time the spores can swim. They swim about for a time in the wet leaf mold or soggy wood, then again flow about.

In the seaweeds, in mosses, ferns, and seed plants, there are asexual spores, that is, spores which are capable of growing directly into a new plant without union with any other mass of living material. For example, in mosses asexual spores are borne in a capsule (sporangium), and these spores grow into the moss plant, which in turn develops eggs and sperms. In ferns, asexual spores are borne in cases which, grouped together, form the brown "warts" on the back of fern fronds. These spores germinate, developing a small heart-shaped structure, which in turn is the bearer of male and female organs. In seed plants there are also asexual spores, as well as sexual bodies. There are small asexual spores in the anthers which develop into pollen grains (male plants); and large asexual spores in the ovules which develop into embryo sacs (female plants).

Problem 7. How are plants propagated artificially?

The multiplication of plants artificially is commonly known as **propagation.** Among our common seed plants there are two distinct methods of propagation: (1) **by the use of seeds**, and (2) **by the use of some vegetative organ**, such as stem, or root, or leaf.

We have learned that in the seed there is an embryo, or young plant, and that it is formed as a result of the process of fertilization. The embryo of the seed is a result of the union of two sex elements. One of these elements, the pollen grain, may or may not have come from the plant which bears the seed; if it did not, then the embryo in the seed has characters of two parents. This means that, when a plant is cross-fertilized, the resulting seeds will produce plants in many particulars **unlike** the parent which bears them. **Propagation by seeds is a sexual method.**

On the other hand, when a plant is propagated by means of stems or roots or leaves, we may be certain that the parts used will produce plants closely resembling those from which they were taken. **This method of propagation is vegetative.**

Let us cite an example which further distinguishes between the methods of propagation by seeds and by vegetative organs. The pollen of strawberries is carried chiefly by bees; hence there are great chances that the ovules of any particular flower will be fer-

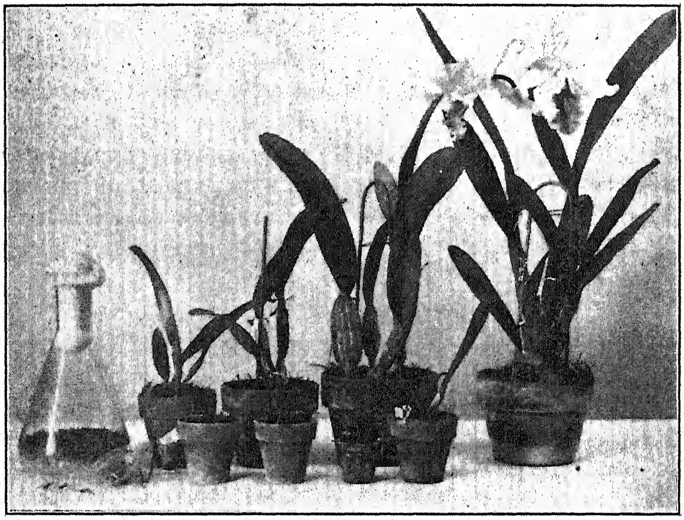

FIG. 108.—Modern method of propagating the tropical orchid. Formerly propagated in cultivation only by vegetative means, orchids are now grown from seed germinated on specially prepared media.

tilized by pollen from another plant. If they are so fertilized, the embryo which results will possess characters of two parents. This accounts for the fact that strawberries when grown from seed seldom come true to type; that is, they seldom are like the parent plant from which the seed was taken. If we wish to propagate a desirable variety of strawberry and keep it "true," we use the "runners" or vegetative parts. Runners are merely "chips off the old block."

Propagation by the use of vegetative organs is practiced if the

plants do not come true from seed. This is the case with hybrids and many horticultural varieties. Also a number of plants such as sugar cane, banana, sweet potatoes, and Irish potatoes seldom produce seed and, of course, must be propagated vegetatively.

In propagating plants by vegetative means, use is made of **stems**, of **roots**, and of **leaves**. Many more plants can be vegetatively propagated by stems than by roots or leaves. A stem structure usually may be readily distinguished from a root as follows: The stem is divided into definite joints and the buds, hence, the branches arise in regular order; the buds occur in the axils of the leaves. Roots, on the other hand, do not have definite joints, and usually bear no buds or leaves. Relatively few plants can be propagated by means of their roots. Among them may be mentioned the sweet potato, dahlia, raspberry, and certain blackberries. Rarely, the leaf may be employed as a propagating organ. A striking example is seen in begonia and Bryophyllum.

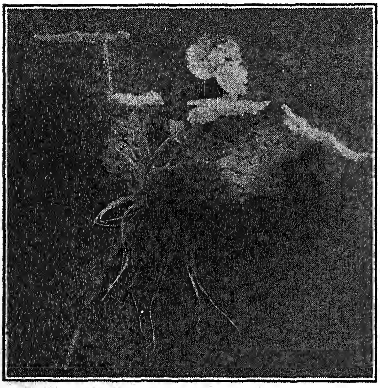

Fig. 109.—Vegetative reproduction of *Tolmiea menziesii* from a leaf.

Propagation by separation. In this process of propagation use is made of such vegetative parts of the plants as become detached **naturally**. These include such structures as bulbs, bulblets, bulbels, corms, and tubers. Each of these possesses one or more buds which, under proper conditions, are capable of growth.

Exercise 100. Propagation by separation. Study bulbs, bulbels, bulblets, corms, and tubers. These should be brought to the laboratory, their structure studied, and some set out under conditions favorable for growth. Talk with a plant propagator in a greenhouse concerning methods of growing them and their use in multiplying plants commercially by **separation.**

Bulb. A splendid example of the bulb is the onion. Examination of the mature bulb of the common onion shows it to be made

up of the much-thickened bases of leaves, attached to a small cone-shaped stem. These scale leaves are quite rich in food material. The bulb possesses a terminal bud and occasionally lateral buds in the axils of the leaves.

Bulbel. Often a number of small bulbs will develop about a large mother bulb. These are called bulbels. For example, in the white lily (*Lilium candidum*) a group of bulbels is formed at the top of the mother bulb, and each produces a number of roots. These bulbels may be separated from the mother bulb, and each used to propagate a new plant.

Bulblet. These are small bulbs which are developed above ground, usually in the axils of leaves or in the flower group. They do not differ essentially from bulbels except in their position on the plant. In the tiger lily (*Lilium tigrinum*) small bulbs occur in the axils of the leaves; they may be removed from the parent plant and used for the purpose of propagation. In "top," "tree," or Egyptian onions, clusters of bulblets are developed at the top of the flower-bearing stalk. They will grow while still attached to the stem, but, of course, are detached for the purposes of propagation.

Corm. This type of stem is well exemplified in the crocus and gladiolus. It is a short, solid underground stem, differing from the bulb in the absence of scale leaves. The corm is usually flattened from top to bottom and bears a cluster of thick fibrous roots at the lower side and a tuft of leaves on the upper side. A number of small corms, called cormels, may develop on the mother corm. Both the large corm and the cormels may be used in propagation.

Tuber. The best example of the tuber is the common Irish potato. It is a simple enlargement of the tip of a slender underground stem. The buds of the potato tuber usually occur in groups, each group being called an "eye." The potato plant may be propagated by planting the whole tuber, or by cutting it into pieces, each piece having one or more "eyes."

Propagation by division. In this method of propagation, living vegetative organs are artificially broken or cut into sections, or pieces, and these placed under conditions suitable for growth. For example, as cited previously, the tuber may be divided into a number of pieces, each having one or more eyes (buds), and these

may be employed to propagate the plant. Plants such as canna, iris, asparagus, rhubarb, and ferns which produce horizontal underground stems (rhizomes or rootstocks) may be readily propagated by dividing these into a number of sections, each of which bears several buds. Most of our perennial herbs may be propagated by division of the " crown." The name " crown " usually applies to that part of a perennial plant which is just below or at

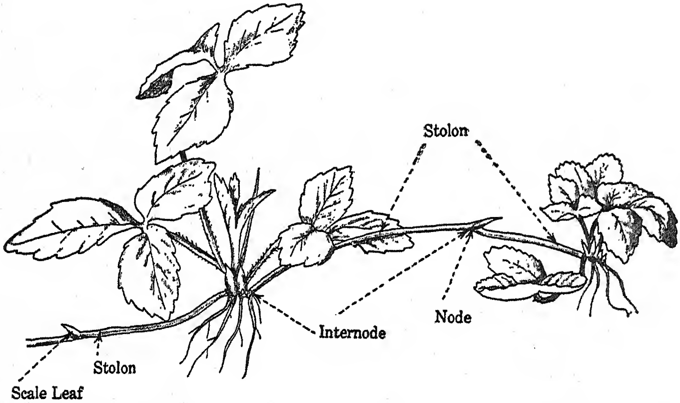

FIG. 110.—A strawberry plant showing propagation by means of "runners" or stolons. (From Holman and Robbins, in A Textbook of General Botany.)

the ground surface, and which is essentially a clump of shortened stems bearing buds and roots.

Exercise 101. Propagation by division. Propagate certain of the following plants by division: potato, canna, rhubarb, ferns, columbine, larkspur.

Propagation by cuttings. In this method, some vegetative part of the plant is detached and placed under conditions favorable for growth. Cuttings may be made from stem, root, or leaf. Of course, the cutting must contain living tissue, have a certain amount of stored food for growth, and be capable of developing growing points. The growth of the missing organs from a cutting is **regeneration.** It is believed that any vegetative part of a plant (stem for example) which possesses active, growing cells has the power of regenerating the missing organs (roots, leaves, and

flowers) if placed under proper environmental conditions. Failures are probably due to our inability to create satisfactory growth conditions. We have learned by experience that some plants can be propagated easily by stem cuttings, others by root cuttings, and a relatively few by leaf cuttings. We can not always tell by observation of the plant whether or not these organs can be used to propagate its kind. We are still unable to offer a satisfactory ex-

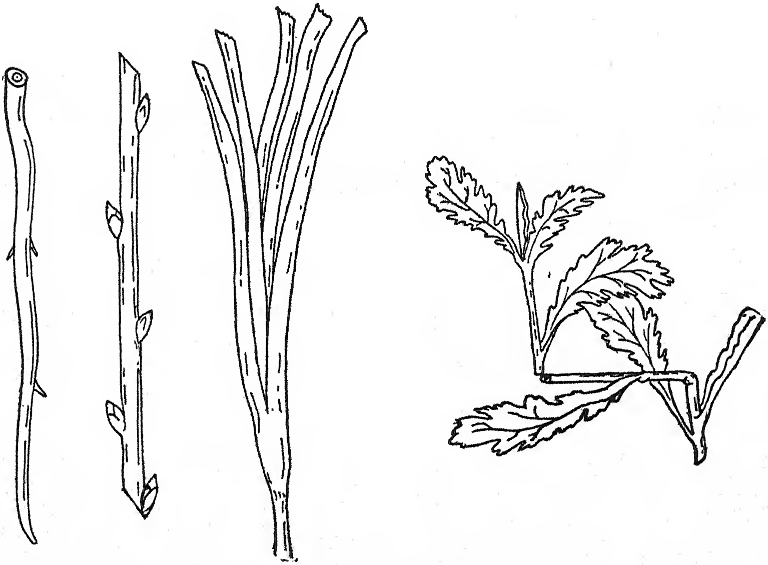

FIG. 111.—Root and stem cuttings. From left to right: root cutting, hard-wood cutting, soft-wood cutting, and soft-wood cutting showing proper and improper age of stem from which cutting is to be made; the stem should snap in two when bent, as shown at the left of the leafy stem, rather than crush, as shown at the right. (Figure at right redrawn from Kains, in Plant Propagation.)

planation why root cuttings of such plants as the blackberry and red raspberry will readily produce buds, whereas those of many other plants under the same conditions lack this power.

Cuttings should be placed under conditions favorable for the rapid healing of the cut surface. When a stem is cut in such a way as to involve the growing layer or cambium, the cambium is stimulated to active growth and forms a mass of large, thin-

walled cells known as **callus**. It is generally believed that callus formation must precede the development of roots, although it is known that roots do not arise directly from callus tissue. A new cambium arises by differentiation of inner callus cells, and as a rule it is from this cambium that the growing points of roots and stems originate. However, best results are usually obtained from callused cuttings. At any rate, the conditions which favor the development of callus also favor root formation.

Stem cuttings. These may be made from:

1. **Mature or dormant** growth, that is, from hard or ripened wood, or from

2. **Immature growth,** that is, from soft wood or from herbaceous stems which are vegetatively active.

As a rule, in cuttings of mature growth, wood of one season's growth is employed, although sometimes wood two or more years old is used. Cuttings are usually made from 6 to 10 inches long, although they may be longer or shorter. Each cutting should possess at least one but preferably two or three buds. It is advisable to cut the lower end just below a bud. The cuttings are usually made in the fall or early winter. They are then stored in a place that is warm and moist enough to allow callus formation and some root growth but not warm enough to permit bud growth. Root growth will proceed at temperatures too low for bud growth. It is often the practice to bury the cuttings, in bundles, with the uppermost buds downward. Thus the cut end of each stem is near the soil surface, which, being warmed first in the spring, stimulates the development of roots. Cuttings should be set out in the spring before the buds open.

It is possible to propagate most plants from immature growth although greater care is often required to get them to root than is necessary for hard-wood cuttings. Stems should be used that are neither too hard nor too soft, but break with a snap when bent. Such plants as begonias, coleus, geraniums, and chrysanthemums are propagated by green cuttings, or so-called slips. They are usually grown in hotbeds or greenhouses. It must be kept in mind in the growing of cuttings that the tissues above ground are subject to the loss of water for a period before there is root development and sufficient water absorption. This makes

it necessary that the water-losing surface be reduced by removing most of the leaves, and that the cuttings be protected in some way from drying out. The small leaf surface that is left on the plant manufactures food that is used in the formation of roots.

Root cuttings. Many plants can be propagated by means of root cuttings. The sections of the plants used in this case do

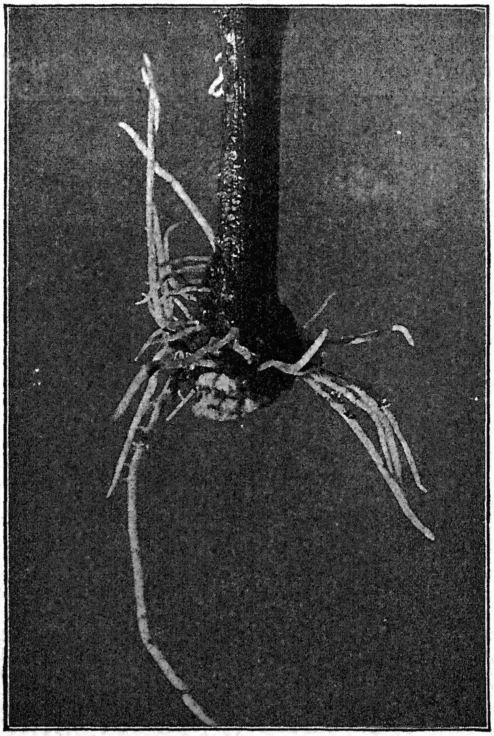

FIG. 112.—A stem cutting, showing the independence of root and callus formation. (From Bioletti, in Calif. Agr. Exp. Sta. Bulletin.)

not possess buds. Buds develop during growth of the cutting. Root cuttings are planted shallowly, about ½ to ¾ inch deep. Among plants that can be propagated by root cuttings may be mentioned the blackberry, red raspberry, horseradish, willows, poplars, osage orange, plums, cherries, and juneberry. Generally

those plants which have a tendency to produce suckers from the roots can be propagated readily by means of root cuttings.

Leaf cuttings. A number of plants, chiefly ones with thick, fleshy leaves, can be propagated by means of leaf cuttings. Among such are begonias, bryophyllum, gesneria, and gloxinias. The leaves may be cut into a number of pieces, each including a part of a main vein. Under proper growth conditions the ends of the veins callus, and roots and buds are developed. In bryophyllum, the whole leaf may be used, without cutting the veins; when this is placed in contact with moist sand, roots and buds are formed at the notches. (See Fig. 109.)

Exercise 102. Cuttings. Each student should propagate a number of different plants by cuttings, including stem, root, and leaf cuttings. Suggested material is as follows: stem cuttings: chrysanthemum, geranium, carnation, coleus, begonia; root cuttings: horse-radish, willows, cherries, blackberry, dandelion; leaf cuttings: begonias, bryophyllum, gloxinias.

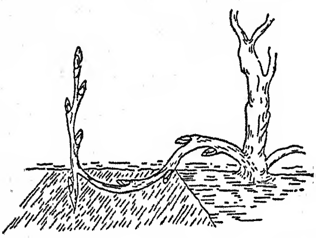

FIG. 113.—Propagation by layering. A branch is bent down and partly buried. It is here shown wounded, which seems to hasten root development. (Redrawn from Kains, in Plant Propagation.)

Propagation by layering. This is a method by which the plant is propagated on its own roots. It consists of bending over a portion of a branch and covering it with soil to keep it moist. Roots develop at the nodes that are covered, and buds develop at these rooted nodes. The section of the stem thus rooted may be severed from the parent plant and lead an independent life. In many plants, rooting of the buried stem may be hastened by injuring it. This appears to limit the movement of food and brings about its accumulation above the point of cutting from which roots develop. Plants which root readily at the nodes, when their branches come in contact with moist earth, are easily propagated by layering. As contrasted with cuttings, the layer is attached to the parent plant, and thus derives water and food from it until it becomes established. It is a more certain mode of propagation than that

of cuttings. Among plants which are commonly layered are wisterias, honeysuckles, grape, passiflora, raspberry, and hydrangea.

Exercise 103. Layering. Propagate by layering some plant such as grape, raspberry, hydrangea, English ivy, or honeysuckle.

Propagation by suckers. In the strict sense a sucker is a stem arising from an adventitious bud which develops on a root. The term is sometimes wrongly extended to include branch stems from

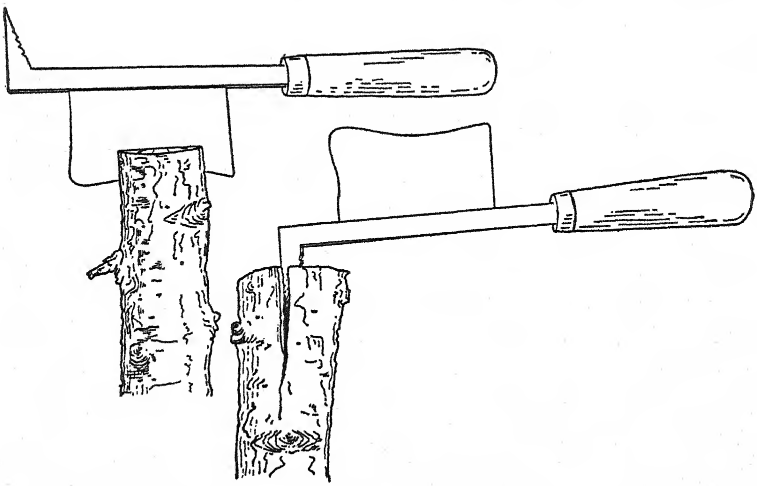

FIG. 114.—Cleft grafting. Left, making cleft; right, cleft being held open for inserting scion. (From photograph by Division of Pomology, College of Agriculture, University of California.)

the base of the plant. Among plants which develop suckers may be named the silver-leaf poplar, black locust, blackberry, red raspberry, and plum. Propagation by suckers involves cutting off a portion of the root which bears the sucker, and transplanting.

Propagation by stolons or runners. A stolon or runner is a stem that grows more or less horizontally along the surface of the ground. The best common example is the strawberry. This plant naturally propagates itself by means of runners. A runner

sent out from the parent plant produces both roots and new shoots after which the runner may die, thus severing the daughter plant from the parent. The young plants which form at the rooting nodes of the runner may be cut off and set out. Stolons form roots naturally, but rooting may be hastened by covering them with soil. It will be readily observed that the layer is in reality an artificial stolon. (See Fig. 110.)

Exercise 104. Suckering and propagation by runners. Observe in the field the suckers of such plants as mentioned in the foregoing paragraph. Cut off a portion of a root which bears a sucker, and transplant. Also observe in a strawberry bed how the plants naturally propagate themselves by runners.

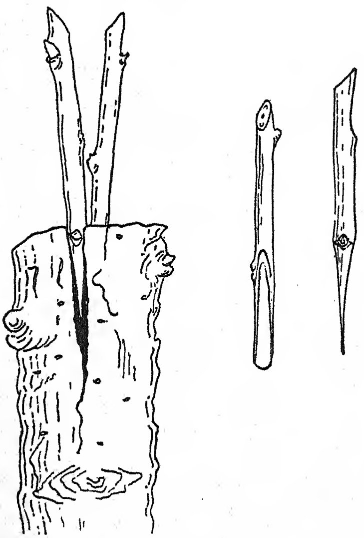

FIG. 115.—Cleft grafting. At right, two views of the scion, and at left, the scions in position in the cleft of the stock.

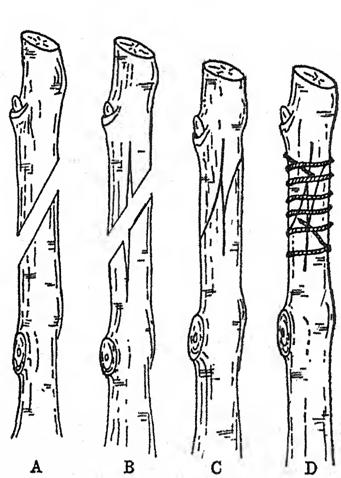

FIG. 116.—Steps in tongue or whip grafting.

Propagation by grafting. This is a very old horticultural practice, and is in common use in propagating fruit trees. The fruit grower, in order that he may be certain as to the variety

he will have, propagates them vegetatively, one of the chief ways being by grafting. The operation may also be carried on in order to change the size of the tree. For example, when pears are grafted on the more slowly growing roots of the quince, the stock retards the growth of the pear, and dwarfing results. Another object of grafting is to grow desirable varieties on disease-resistant roots, or on roots which will adapt the plant to various soil conditions. For example, the northern California black walnut is resistant to a soil fungus (mushroom) known as *Armillaria*, whereas the English walnut is not so resistant to the organism; this is one

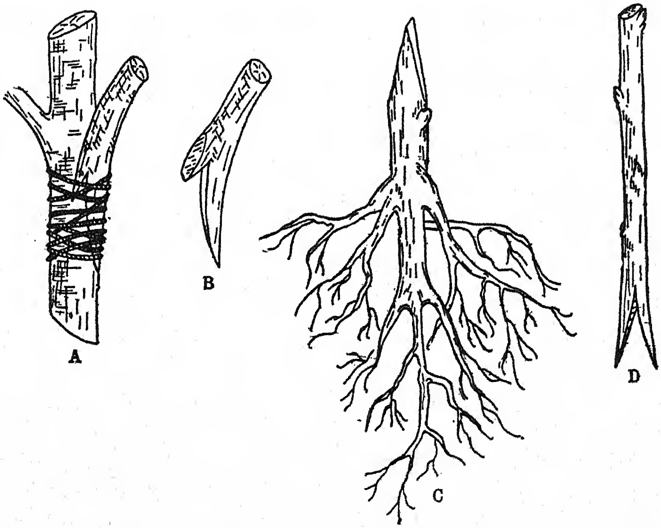

FIG. 117.—A and B, side grafting; C and D, saddle grafting. (Redrawn from Newsham.)

reason for the practice of grafting the English walnut on black walnut. The Northern Spy variety of apple is resistant to the woolly aphis which attacks the roots. This variety is used as a stock upon which to graft less-resistant kinds. The common peach is sometimes grafted on Davidiana root because of the latter's resistance to alkali.

Three kinds of grafting are recognized: **scion-grafting**, **bud-grafting**, and **approach-grafting**. In scion-grafting, a stem called the **scion**, containing several buds, is attached to another rooted stem or root, called the **stock**, in such a way as to bring the growing layers (cambiums) of each together. After a time there is a union of the stock and scion. In **budding**, the scion is a single bud together with a small strip of bark. This is attached to the cut surface of the stock so as to bring the growing layers of stock

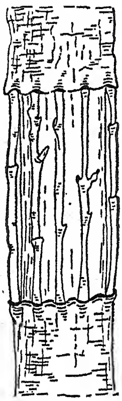

FIG. 118.—Method of bridge grafting in a girdled trunk. Scions are inserted under the bark, thus bringing about a bridging of the girdled zone. (Redrawn from Solotaroff, in Shade Trees in Towns and Cities.)

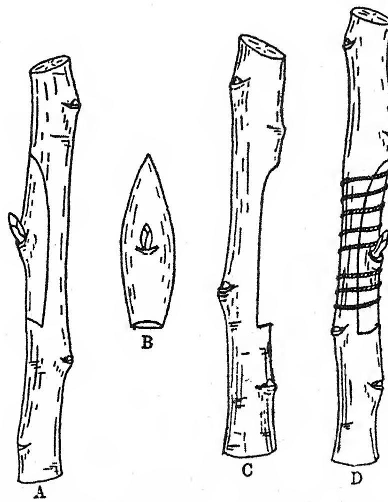

FIG. 119.—Steps in patch budding, often used with walnuts.

and scion together. **Approach-grafting**, also sometimes known as **inarching**, consists in uniting two plants while they are still growing on their own roots. It is obvious that this is possible only between plants which are standing close together, or between different parts of the same plant. As a rule, approach grafting is executed by removing a piece of the bark, down to the cambium, of the two stems to be united, and binding these two cut surfaces together. After the two have grown together, the scion is cut off below the union, and the stock above the union. Care should

be taken to sever the scions gradually in order that growth will not be retarded.

It is well known from experience that certain plants can be grafted upon one another, whereas others are united with difficulty. For example, peach can be grafted on the plum, but it can not be grafted on the apple. As a general rule, the more closely two plants are related botanically, the better are the chances of

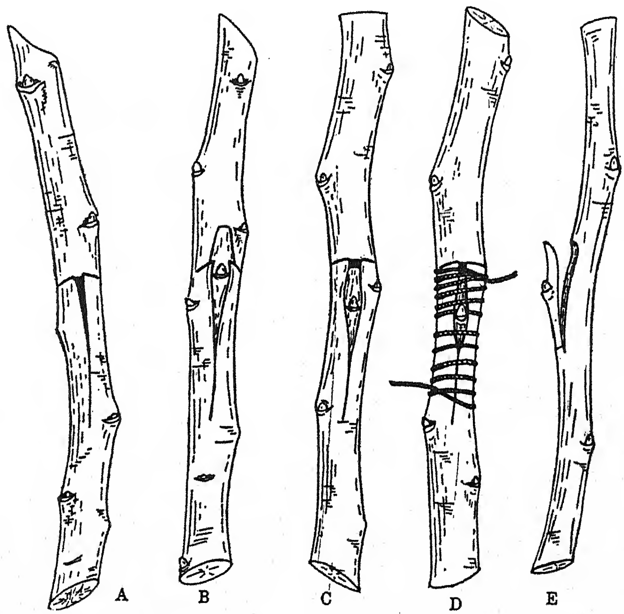

FIG. 120.—Steps in shield budding. A, the T-cut in the stock; B, inserting bud; C, bud in place; D, bud tied; E, bud stick, showing bud ready for inserting in stock.

a union by grafting. Plants belonging to different families can not be grafted. For example, it is impossible to graft the peach, which is a member of the rose family, upon the walnut, a member of the hickory family. Plants belonging to different genera within the same family may or may not unite readily. For example, in the rose family, the peach will unite well with the plum, but

not so satisfactorily with the apricot. The tomato and the potato may be intergrafted; they represent different genera in the family *Solanaceae*. Plants belonging to different species within the same genus, as for example, crabapples and common apples, usually form a satisfactory graft union. And different varieties of the

FIG. 121.—A budded apricot tree. (Photograph furnished by Division of Pomology, California College of Agriculture.)

same species, as for example, the different varieties of peaches, may be grafted upon one another. In short, as a general rule plants belonging to varieties of the same species graft upon one another with greater certainty than plants of different species of the same genus, these in turn with greater certainty than those belonging to

different genera of the same family; and plants belonging to different families will not unite at all by grafting.

It should be kept in mind that, when two plants are united by grafting, each keeps its individual characters. If the crabapple (scion) is grafted on the common apple (stock), the branches which arise from the scion will bear crabapples, and those from the stock common apples.

FIG. 122.—Approach grafting, also known as inarching. The stock and scion are bound together, cuts being made in each (two stems at left), exposing the cambiums, to hasten union. (Redrawn from Kains, in Plant Propagation.)

In grafting, the stock may be the root, the crown, the main stem, the main branches, or the tips of the branches. There are many methods of joining the stock and scion, among which are the following: whip or tongue, cleft, bark, kerf, veneer, splice, saddle, and bridge. In all these methods, care is taken to bring the growing layers together and have them touch at as many points as possible.

What are the purposes of grafting? Navel oranges are seedless; how is the variety propagated? How can the life of a tree girdled by gophers be saved?

Suggested activity. Prepare a demonstration of different kinds of grafts using a large square of heavy cardboard to mount the prepared material.

Problem 8. How did reproduction by means of sex in plants originate?

There is strong evidence that millions of years ago the only plant life of the world was slimy masses of one-celled organism, that the type of plant life of prehistoric waters and muddy shores

was composed exclusively of sexless species. In our modern world, plants which probably most resemble these organisms are the blue-green algae, many of which grow in hot springs, withstanding temperatures which would kill most other modern plants. Flowering plants as we known them today, and pines and spruces, even ferns and mosses, formed no part of the scanty vegetation of those early-day landscapes. After millions of generations of asexually reproducing organisms, sexual reproduction came into existence. Scientists believe that it arose independently in several different kinds of plants and animals.

Even today there are some plants in which sexual reproduction is so primitive that it seems that it can not have changed very much through all the ages since sex first appeared. One such plant is *Ulothrix.* This is an alga, whose fine green, almost microscopic threads grow anchored by a holdfast cell to sticks and stones in moving water. The *Ulothrix* cell is able to organize its protoplasmic contents into several masses. These peculiar bodies break through the hard outer shell of the cell and swim away. The original cell is thus divided into several naked cells, each propelled by microscopic arms of protoplasm. Most of them swim and find favorable surfaces upon which to anchor and gow into new individual filaments. These cells are **spores.** They are asexual bodies in that they are capable of growing into plants, just as are those in moss capsules and those on the under sides of fern fronds.

The spores of *Ulothrix* are not all alike. This is significant. They vary in size. The number of spores from a single cell may vary from one to thirty-two. If one spore is produced, this means that the entire protoplasmic body underwent no division, but was freed from the cell. If thirty-two spores are formed in a single cell, this means that the mother mass of protoplasm underwent five successive divisions. These spores are, of course, very small and contain very little stored food. Associated with these size differences are amazing differences in behavior. Large spores and those of intermediate size behave as asexual spores, that is, develop directly into a new individual *Ulothrix* plant. The smallest spores, however, are apparently incapable of developing into a new plant. If a drop of water containing these smallest bodies,

swimming or squirming about, is examined with a high-power microscope, they are seen behaving in a most extraordinary fashion. They are coming together in pairs, a mating of the most primitive sort, and each pair is fusing to form a single cell. This new cell, formed by the union of two, now has the power of growing into a *Ulothrix* plant. Separated, the smallest spores perish; united they are strong enough to carry on the race.

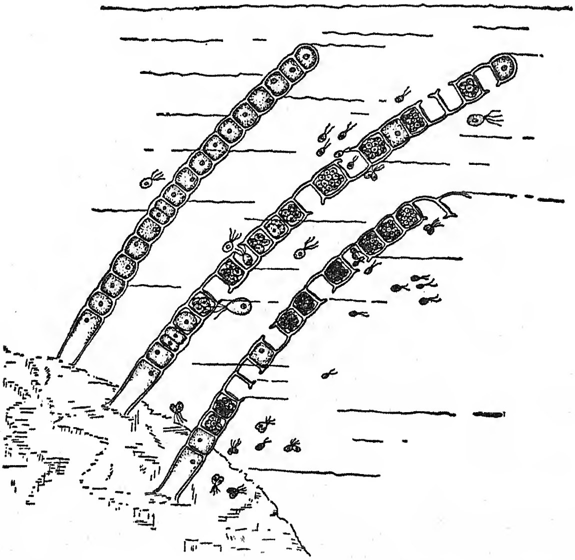

FIG. 123.—From one to thirty-two naked cells may swim out of a single Ulothrix cell. The larger, four-armed ones are able to make a go of it by themselves, but the smaller ones must first undergo the simplest sexual process known. Several are shown engaged in mating. (From Robbins and Pearson, in Sex in the Plant World.)

The mysteriously rejuvenating fusion of spore-like bodies which we call gametes in *Ulothrix* is the most primitive form of sex act known. In the development of the plant kingdom, when a spore first behaved as a gamete, sex originated. Thus **sex originated in the plant kingdom merely as a modification of an asexual method.** It is significant that, once sexual reproduction appeared among primitive plants, it apparently gave them and their offspring

which inherited sexuality such an advantage in the struggle to populate the world that they did not die out. On the contrary, sexually reproducing plants have gone a long way towards "inheriting the earth."

In a primitive plant like *Ulothrix*, sex probably originated. In this plant the gametes are to all appearances similar. But in sex development in the plant kingdom, one gamete becomes a small, motile sperm, the other gamete becomes a large motionless egg. In all plants, in seaweeds, in mosses and liverworts, in ferns and lycopods, sperms have fundamental likenesses; they are small, motile, and have very little stored food. Eggs on the other hand are relatively large, inactive, and rich in stored food. The fusion of an egg with a sperm is the process of **fertilization**. Ordinarily a sperm alone, or an egg alone, is incapable of developing into a new individual, but once an egg has united with a sperm the fertilized egg is able to develop into a new individual.

ADDITIONAL QUESTIONS

1. Why do insects visit flowers?
2. Of what use are the bright colors of flowers.
3. Name five plants which produce more than one kind of flower.
4. What is the difference between pollination and fertilization?
5. What is meant by the expression: "The flower is not a sex organ?"
6. It has been observed that apples, even in a good season, set no more than 5 per cent of fruit. Explain.
7. Why does a strawberry bed sometimes fail to fruit well, although flowers are produced in abundance?
8. Are berries found on all sassafras trees? Explain.
9. Describe the course of the pollen tube.
10. Why do the seeds of fruit trees so seldom produce offspring true to the stock?
11. In a "double" rose, what is the origin of the extra petals? How does such a plant reproduce?
12. Why are several varieties of pears often planted together in an orchard?
13. Which are the most important hay-fever plants, those which are wind-pollinated or those which are insect-pollinated?
14. What is the general relation between the height of a plant and its method of pollination?
15. Flowers are frequently clustered. What is the advantage of this?

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UNIT VI

THE DEPENDENCE OF PLANTS ON THE CONDITIONS OF THEIR SURROUNDINGS

As humans, our daily life, our health, our capacity for doing work, our happiness—all are influenced by the conditions about us. The food we eat, the temperature and humidity of the room in which we work, the light by which we read, the people with whom we come in contact—all have an effect upon our life. The sum total of our surroundings we call the **environment.** We can not escape it. Everything we experience with our senses—see, feel, touch, hear, or smell—is a part of our environment and has its influence upon us.

So it is with plants. Their growth and development, and all the associated activities, are influenced by the various factors of the environment. The principal factors influencing plants are: (1) **water,** (2) **heat,** (3) **light,** (4) **soil,** (5) **air,** and (6) **organisms,** both plants and animals. The environment is a complex set of factors. All these factors are operating at once upon the plant. How the plant behaves, and what its structure is, are determined not by water alone, or light alone, or any other single factor alone, but by all of them exerting their influence at the same time.

Problem 1. What is the importance of water to plant life?

Life without water is impossible. Water is just as essential to plants as it is to animals. Water is the principal part of all living tissue. It constitutes about 80 to 90 per cent of the weight of protoplasm (living material). Protoplasm becomes less and less active as water is removed, until a state of dryness is reached which causes death.

Water in the living cells maintains their turgor, which condition is necessary for their proper functioning. A plant does not

manufacture food, and grow, unless its tissues are well filled with water. A wilted plant is inactive. Moreover, the combined turgor of all cells maintains erectness in plants. The brittleness of young plants is partly due to water pressure within the cells.

All materials which move from one part of the plant to another must be in a watery solution. All mineral salts must be dissolved in water before they can enter the plant through the root hairs. Also, oxygen and carbon dioxide can not enter or leave the plant cell except in solution.

As we have seen, water is an essential raw material in the manufacture of food. That is, many of the organic compounds which occur in plants are formed by the chemical combination of water with certain inorganic compounds which are absorbed by the plant from the soil and air. But, as we shall see later, the amount of water actually found in a plant is a very small fraction of the total amount which is absorbed by the roots; a large portion passes through the plant and out through pores in the leaves to the atmosphere.

Water is the chief limiting factor in the growth of most crops. The farmer, except in the most rainy sections of the country, is usually confronted at some time during the season with a shortage of water. This is particularly true in arid and semi-arid regions.

Water is a most important factor determining the character of plants upon the earth's surface. The striking differences in the vegetation of the high mountains, the dry plains, the prairies, the eastern deciduous belt; in the character of the plant life of tropical rain forests, deserts, and tundra; in the vegetation of hillside, brook-bank, gravel slope, bog, meadow, and open water are largely due to differences in the available water supply.

Amount of water in plants. The amount of water in different plants varies widely. As a rule, plants growing under dry conditions contain less water in proportion to their total weight than plants growing in wet situations. However, many desert plants, such as cacti, may possess large amounts of stored waters. The percentage of water is usually greater in young, growing parts than in older portions of the same plant. Seeds and woody tissues contain less water than the leaves or young roots and stems. Toughness of tissue is usually associated with a low water content of the

tissue. Succulency and tenderness of tissue usually signify a high water content.

Exercise 105. Determination of water content of plant parts. Determine the water content of the following plant parts: (*a*) fruit of apple, (*b*) potato tuber, (*c*) grain of corn, (*d*) green leaves of any plant, (*e*) twigs of any woody plant, keeping bark and wood separate. (1) Weigh and record weight of vessels to be employed. (2) Cut or break up the material finely, place in container, weigh immediately, and record. (3) Place in constant-temperature dry-oven, and dry at a temperature of 90° C. until a constant weight has been attained. (4) Record dry weight. (5) Compute percentage of water. Why must care be taken not to subject the tissue to too high a temperature? What is the difference between **dry matter** and **ash** of a plant?

The water problem of the plant. It is quite clear that one of the chief problems of a plant is **to take in at least as much water as it gives off.** Of course, the intake must exceed the outgo, for some of the water is used in the plant. However, absorption must at least equal transpiration (the water-losing process in plants) if the plant is to maintain life. The great dangers that confront most plants, particularly dry-land plants or those subject to dry periods, are too little absorption or too much transpiration. A plant dies when the rate of water loss exceeds the rate of water intake for any length of time.

There is a stream of water through the plant from root hairs to leaves. Its rate of flow may be limited or restricted at two points: (1) at the point of entry (root hairs); and (2) at the point of exit (leaves). Plants withstand dryness in two general ways: (1) by increasing the amount of water taken in through the roots; (2) by limiting or retarding the amount of water lost from the plant.

The wilting of plants. The importance of water in the plant's life is well shown by the phenomenon of wilting. A plant tissue is made up of a mass of cells. When a cell is filled with water and various materials in solution, its walls are bulged outward and we say that the cell is **turgid.** If the water is removed from the cell, it becomes flaccid and wilts. If all the cells of a herbaceous plant are filled full of water, each cell wall being stretched out because of the pressure from within, the plant as a whole stands erect. Of course, it must be understood that most plants possess

strengthening woody tissue and are not entirely dependent upon turgor to hold them in an erect position. But the leaves of all plants and the young stems of herbaceous plants are largely dependent upon the turgor of the cells for their rigidity.

When a plant wilts, water is not being absorbed as rapidly as it is being used or lost. Its cells are not full. The freshness and crispness of lettuce, for example, are associated with turgidity of the leaves. Any condition by which transpiration can be checked, such as by a cool atmosphere laden with moisture, will prevent wilting to a large extent.

Exercise 106. Loss of water from leaves. Place a handful of fresh, green leaves, free from water on the surface, under a bell jar. Set up at the same time and in the same way a bell jar which has no leaves. Place both in a window. After 30 or more minutes examine for presence of moisture on the inner surface of the jars. How do you account for what you see? Does the water come from the leaves? In what form does moisture escape from the leaves? Why do leaves become limp when they lose water?

Exercise 107. Loss of water from a growing plant. Secure a small, vigorous, potted plant. Cover the entire pot with a piece of oiled paper or rubber cloth, fitting it up closely about the stem of the plant and over the soil. This is to make sure that no water escapes from the walls of the pot or surface of soil. Now place a bell jar over the plant and set in a place suitable for growth. From where does the water come that collects on the inside of the jar?

The transpiration stream. All exposed surfaces of the plant are losing water, but **the leaves are the principal transpiring organs.** The water passes off from plants in the form of water vapor.

In many respects transpiration resembles evaporation, such as takes place from a free water surface. It is different from evaporation, however, in that it is controlled in part by the plant itself. For example, the rate of water loss, by transpiration, from a living plant is less than the water loss, by evaporation, from a dead plant. And the amount of water lost from a given area of leaf is less than that lost from an equal area of free water surface. Why? For example, it was found, for one plant, that a given area of free water surface lost about ten times as much water in an hour as an equal area of leaf surface. As we learned in Unit II, the living plant has numerous pores (stomata) in the epidermis of the leaves which open and close with changes in the conditions of the surroundings.

Although water loss is a constant danger to the plant, the process plays an important rôle in that it maintains a stream of water (the transpiration stream) from the roots to the leaves, and throughout the entire plant body. There has been a general impression that, the greater the rate of transpiration, the greater the rate of intake of mineral salts by the root hairs. It has been shown by careful experiments, however, that an increase in the rate of transpiration does not proportionately increase the quantity of mineral nutrients absorbed. For example, if, by being placed in a dry atmosphere, a plant is caused to absorb and transpire water at double its former rate, the mineral salts absorbed are increased in amount, but are by no means doubled.

How does water get out of the leaf? We have learned that surfaces of leaves are covered with an epidermis or skin composed of box-shaped cells, the outer walls of which are thicker than the inner and side walls, and often waxy in nature, such that they effectively prevent the loss of water through them. Here and there in the epidermal layers of the leaves are small openings or pores, known as **stomata** (Figs. 28, 29). Each pore or stoma is bordered or guarded by two cells, which differ from all other adjoining cells in their shape, in the possession of green coloring matter, and in their behavior. In most plants these two **guard cells** of each stoma or opening are capable of changing their shape, and by so doing bringing about the opening or closing of the pore. In a wilted plant the stomata are usually in a fairly closed condition, and hence the opportunity for water loss is reduced.

There are usually more stomata on the under surface of a leaf than on the upper, and in some plants there are none at all on the upper surface. For example, in the apple leaf there are no stomata on the upper surface, whereas on the under surface there are approximately 161,000 per square inch. What is the advantage of this? In corn there are about 60,000 per square inch on the upper surface and 102,000 per square inch on the under surface. It has been computed that in a single corn plant of average size there are approximately 104,057,850 stomata in the epidermis or skin of its leaves.

There is some slight loss of water through the waxy cuticle of

a leaf, but most of the water loss is through the stomata. This is well demonstrated in the following exercise.

Exercise 108. The loss of water from leaves is chiefly through stomata. Take three fresh green leaves of the common rubber plant (*Ficus elastica*) of conservatories. In this plant the stomata are confined to the lower surface. Smear vaseline on the upper surface of one leaf and on the lower surface of a second; and keep the third leaf free from vaseline on both surfaces. Hang them up by the leaf-stalks. Observe the results at various intervals of one, two, three, five, and ten days. Discuss.

The amount of water lost by plants. The amount of water that is absorbed by plants, passed through their body, and out through the stomata to the air is enormous, and really much greater than most people realize. It was computed that a single corn plant during one growing season lost 54 gallons of water. A perfect stand of corn would be about 6000 plants per acre, so the total amount of water that would be evaporated from the leaves and sheaths of an acre of corn during the growing season would be 324,000 gallons, or 1296 tons. Disregarding all other losses of water from the soil, how many inches of rainfall would it require to supply the foregoing acre of corn?

It has been calculated that an average-sized oak may have 700,000 leaves; that about 244,695 pounds of water will pass from its surface in the five months, June to October. In a single year there will pass through the oak tree an amount of water equal to 226 times its own weight.

From which is the most water lost: an area covered with vegetation, or one devoid of vegetation? From the water standpoint, why are weeds injurious in a field of crops?

Exercise 109. Measuring the amount of water lost by leaves. Fill a jar with a measured amount of water. Cover the top with a rubber cloth. Secure a freshly cut healthy peach twig containing approximately 20 to 30 leaves. Cut in the rubber cover a slit just large enough to allow the twig to enter. Allow the cut end of the stem to reach well down into the water. Observe for a period of three or four days. If it is necessary to add more water, measure the amount. Determine for any time interval the amount of water lost from the jar. Does this represent that lost by transpiration through the leaves? Find out from the instructor a simple method for securing the combined area represented by all the leaves of the twig. Estimate the number of leaves on an average-sized peach tree, and from your computation make a

rough estimation of the amount of water lost from the entire tree during a 24-hour period.

The water requirement of plants. Plants differ greatly in the total amount of water which is expended in producing a unit of dry matter, that is, in their **water-requirement**. Some plants, like millet, are economical; others, like alfalfa, are comparatively uneconomical. The water requirements of a number of plants have been determined experimentally. In the following table is given the water requirement of a number of plants under certain conditions as they existed at Akron, Colorado. For different climatic conditions these values will be somewhat different.

	Actual Water Requirement (pounds)
Alfalfa, Grimm	659
Rye, Spring	496
Oats, Swedish Select	423
Barley, Beardless	403
Wheat, Kubanka	394
Wheat, Kharkov	365
Corn, China White	315
Wheat, Turkey	364
Sudan grass	359
Milo, Dwarf	273
Kaoliang, Brown	223
Millet, German	248

It will be observed from this table that alfalfa, for example, uses more than twice as much water to produce a unit of dry matter as does German millet. In general, a plant with a low water requirement is relatively drought-resistant.

Problem 2. What is the relation of temperature to plant life?

It is well known that the amount of heat a plant receives greatly influences its growth. The germination of seeds, the growth of roots, of stems, and of leaves, the opening of buds and flowers, and the development of seeds and fruits all are dependent upon certain temperature conditions. Every process of the plant, including such important functions as respiration, food manufac-

ture, absorption, digestion, and reproduction, is influenced by the temperature. These different functions of the plant, and the growth of various organs, may have different temperature relations. For example, absorption of water and salts from the soil will go on at lower temperatures than will the development of flower structures, and the seeds of a plant will usually germinate at a temperature lower than that which is necessary for the maturing of the seeds of that same plant.

The temperature plays a great part in determining the distribution of plants over the surface of the earth. There is a decrease in the temperature as we go from the equator to the poles, and from low to high altitudes. We recognize the broad zones of vegetation peculiar to the tropics, the subtropics, the temperate zones, and the arctic regions. Plants vary in their resistance to low and to high temperatures. And the yields and quality of orchard, garden, and field crops depend greatly upon the temperature.

Effect of temperature upon growth. When a plant grows, there is an increase in the number of cells and in the size of the cells. Two new cells result from the division of an old one. The two newly formed daughter cells, at first small, increase in size. Of course, the growth of the plant body as a whole is the result of the combined growth activity of the many cells which make up the body. Not all cells of a plant at any one time are growing at the same rate; in fact, they are not all exposed to the same environmental conditions.

Every plant carries on its life processes between certain temperature limits. There is a certain low temperature below which, and a certain high temperature above which, a given plant can not grow. We call these temperatures the **minimum** and the **maximum,** respectively. Somewhere between these two, there is a temperature at which the plant grows to the best advantage. This we call the **optimum.** These three important temperature points are called **cardinal temperatures.**

The germination temperature influences the development of the adventitious roots in wheat. In this plant, the first whorl of adventitious roots forms much nearer the soil surface at high temperatures than it does at low temperatures. The plants in the

former case are relatively weak. Seedlings of wheat, germinated at temperatures just above freezing, develop a root system two to three times as large as those grown at higher soil temperatures.

Exercise 110. At what temperature do seeds lose their ability to germinate? (*a*) Secure seeds of wheat, corn, beans, radish, buckwheat, cherry ("stones"), etc. Place several hundred of each kind of seed in separate beakers or large test tubes and cover with water. Bring each to a temperature of 65° C. and retain at that point 15 minutes. Take out 25 of each kind of seed and place under conditions suitable for their germination. Raise the temperature of the remaining seeds to 80° C. and after 15 minutes arrange test for germination of each kind of seed. Raise the temperature to 95° C., and again after 15 minutes arrange test for germination. Raise the temperature to boiling (100° C.) and repeat the procedure given above. (*b*) Repeat the above experiment, but instead of heating the seeds in water, subject them to a dry heat. A dry-oven may be employed, or a double-boiler may be improvised using two beakers of different size. Compare the results. (*c*) Soak lots of the above seeds in water for 1 or 2 hours. Expose lots of each, both dry and soaked, to different low temperatures. Different low temperatures may be obtained by preparing freezing mixtures of salt and ice. After exposure of seeds to the low temperatures for 1 hour, test their germination. Arrange the results of your tests in the form of a table and give your conclusions.

Exercise 111. What is the effect of temperature on root growth? Place seeds of lettuce, radish, beans, corn, or other plants in germinators and germinate at room temperature. When the roots are about ¼ inch long, place a number of sprouting seeds of each kind at different temperatures. Select certain sprouting seeds, marking their position in the germinating dish, and measure the length of the main root at intervals of 12 hours. Discuss results.

Resistance of plants to low temperatures. It is well known that some plants will withstand a much lower temperature than others. For example, the date palm is usually injured by temperatures below 20° F., whereas most varieties of apples will endure temperatures much below zero, if the tissues are mature and in a dormant condition. It is also recognized that different tissues of the same plant vary in their resistance to low temperatures. In our common woody plants the tissue least resistant to freezing is the pith; the next least resistant is the sapwood; then the bark; and the most resistant, in well-matured and well-hardened stems, is the cambium. However, in actively growing stems, the cambium is not so resistant to freezing as other tissues.

The more water plant tissues contain, the more readily are they killed by freezing. Active, growing tissues have more water

FIG. 124.—Heaters in a California orchard. In certain parts of the country late frosts threaten the blossoms of fruit trees. The United States Weather Bureau issues warnings of approaching low temperatures. Orchardists light the heaters, which may develop enough heat to prevent freezing of the tender blossoms.

than dormant tissues, and consequently are more easily frozen to death. Seeds that are well dried will stand much lower temperatures than seeds filled with moisture. For example, corn often suffers from freezing before the grain is quite dry. If the grain becomes thoroughly dried, it will withstand very low temperatures. Corn containing 10 to 14 per cent moisture may be stored with safety in bins exposed to temperatures considerably below 0° F. A frozen grain of corn may have the appearance of being healthy, but the germ (embryo) may be killed or its vitality considerably reduced. It is very essential that corn seed be given a careful test for germination before planting.

The maturing or " hardening " of plant tissues that takes place in late summer, autumn, or early winter seems to influence the resistance to winter temperatures. Well-matured or " hardened " tissues are more resistant than those not completely matured or hardened. For example, wood that has had late growth and gone into the winter incompletely matured is comparatively susceptible to winter injury.

Gardeners commonly practice the process of " hardening off " their transplants. If a tomato plant is removed suddenly from a warm greenhouse in the spring to the garden out-of-doors, it has little resistance to low temperatures, and the death-point is relatively high. The usual procedure is to move the plants from the greenhouse to a cold frame where the temperature extremes are not so great as in the open; here the plants become adjusted to the lower temperatures and after a period may be planted with safety in the open. After the hardening-off process, the plant is able finally to withstand a lower temperature than if suddenly removed from a warm to a cool situation. Hardened plants differ from tender plants in having in the cells more soluble proteins and more water-imbibing substances.

QUESTIONS

1. The minimum temperature for the growth of rye ranges from 0° to 4.8° C., whereas that of tobacco ranges from 10.5° to 15.6° C. What is the relation of these temperatures to the distribution of these crops in the United States?

2. Discuss the meaning of the expression: " An annual plant may be

said to belong to no country in particular, because it completes its existence during the summer months."

3. What is there about the habit of cereals which makes it possible to grow them in a wide range of climates?

4. Why are partly open buds more easily frozen than dormant buds?

5. What is the purpose of placing straw mulches over such low-growing plants as strawberries?

6. A wet soil is usually a cool soil, whereas a dry soil is usually a warm soil. Why?

7. Cite various ways by which man controls the temperatures about plants.

8. What are the chief factors which account for the difference in the type of vegetation as one proceeds from low to high altitudes, and from low to high latitudes?

9. Cite plants that will withstand very high temperatures.

10. Why is it necessary that seed be thoroughly dry before it is stored for the winter?

11. What are the dangers of an "early spring"?

Problem 3. What is the relation of light to plant life?

We have learned that light is the sole source of the energy without which no single living thing, whether plant or animal, could continue to exist. The enormous amount of energy which comes from the sun, and upon which the life activities of plants and animals depend, is absorbed by the green leaves and other green parts of plants. In the green plant this energy is converted into plant food. The development of a green color and the amount of food manufactured by a plant strictly depend upon the duration and intensity of light.

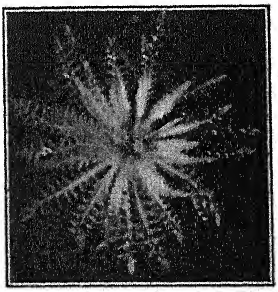

FIG. 125.—Rosette arrangement of the leaves of the purple star-thistle, a weed.

Light also affects the movement and position of plant organs. We are all familiar with the movement of the leaves of a house plant toward the light when placed in a window.

The size and form and structure of plants are also influenced by light. For example, plants growing in intense light often have a dwarf form, with very short stems, whereas plants in light of low intensity usually develop long stems.

The movement and position of plant organs are influenced by light. As stated, the direction of light and its intensity have an effect upon the movement and position of plant organs. Leaves are especially sensitive to light. Many leaves assume a position which will expose a flat surface to the direct rays of light.

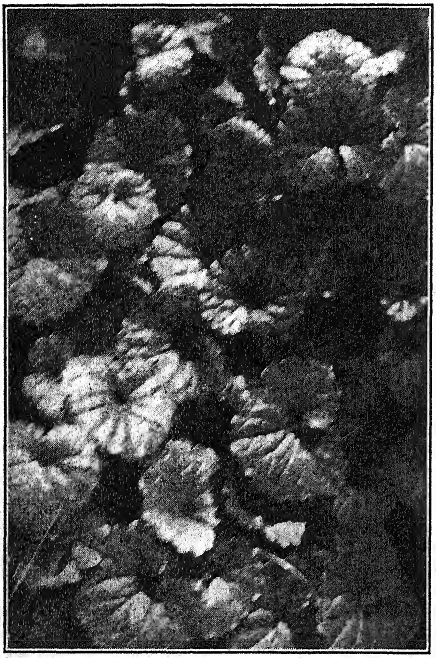

FIG. 126.—Leaf mosaic of ground ivy, showing a minimum of shading.

Exercise 112. Light and leaf position. Observe in the open or greenhouse the relation of shoots and leaves of any plant to light. Observe how the leaves are so arranged that there is little shading of one leaf by another. In fact, the leaves often form a **mosaic.** See Figs. 125 and 126. This is particularly evident in plants that form a rosette, or in climbing plants like ivy which adhere to a wall. Also observe the position of the leaves of the wild lettuce, which on account of intense illumination take a position which exposes their edges to the sun during the hottest part of the day. (Fig. 127.)

Exercise 113. Response of leaves to light. Grow seedlings of lettuce, peas, or beans in a pot which stands in a window, and observe the direction of growth of the plants. Discuss results.

The size, form, and structure of plants are influenced by light. Intense light seems to have a stunting effect. This is shown by the low stature of alpine plants, although other factors, chiefly low temperatures and excessive transpiration, may play a part. Plants in the dark grow long and spindling, which tendency is noticeable, but less so, in the shade. Examine potato sprouts that have developed in a dark cellar. Contrast with those which develop in the light. Why do house plants sometimes grow long and spindling?

There is a marked difference between sun and shade plants of the same species. Trees in the open branch and spread profusely, whereas the same species in the forest, where the light on all sides is cut off, grows taller and produces fewer side branches. How do you account for the splendid form of trees which grow in the open? The leaves of shade plants are thinner and broader than those of sun individuals. What is the advantage of this?

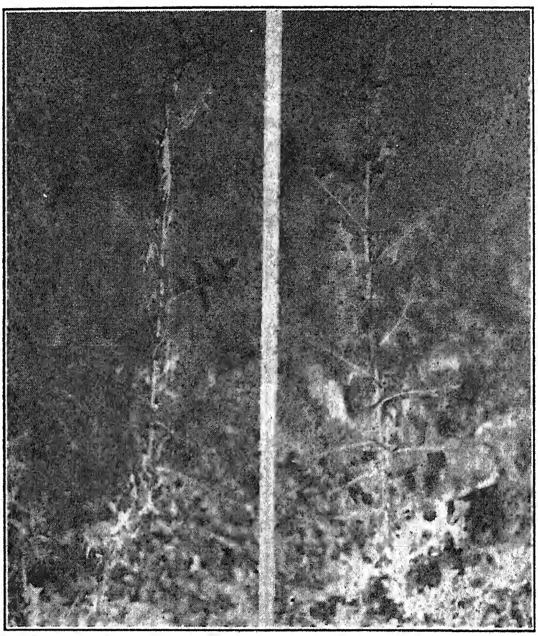

FIG. 127.—Wild lettuce, a compass plant. Left, as seen from south; right, as seen from west. Of what advantage is the habit here illustrated?

As has been stated, in the total absence of light, plants do not develop chlorophyll. The leaves of shade plants, however, are often a deeper green than those of sun plants. This is due to the fact that the epidermal layer of shade plants is thinner than that of sun plants, and consequently the underlying green tissue of the shade leaf shows through. Moreover, sun leaves are

frequently covered with hairs, scales, or a waxy coat which prevent the chlorophyll tissue beneath showing through. Such plants often have a grayish color.

Duration of light. In a discussion of light and its influence upon plant growth, we must take into consideration its **duration**, its **intensity**, and its **quality**. In the arctic regions the summers have long days, but the light intensity is low; at the equator, the daylight period is shorter, but the light is very intense. The long daily period of sunlight at high latitudes, even though the light is of low intensity, makes possible the maturing of splendid grain and vegetable crops. It has been found that the accumulation of carbohydrates in plants, and their rate of growth, are in

Fig. 128.—Response to light. Two views of the same geranium plant. What was the effect of light on the length and position of the stem? How did the leaf petioles respond to light? The leaf blades took a position perpendicular to the incident rays of light.

proportion to the number of hours the plant is exposed to the light, rather than to the intensity of light.

Light intensity. Plants vary greatly as to the intensity of light which they can withstand. Most plants do best in diffuse light; high light intensity is injurious in that it destroys the chlorophyll and thus retards the food-manufacturing process. Many plants, especially in the seedling stage, can not withstand direct sunlight for any considerable period. In full sunlight, the date palm leaf ceases to grow. Normal growth of this organ is made chiefly in the time between sunset and sunrise, but also to a slight extent in daylight when direct sunlight is cut off by clouds.

It has been found by experiment that the Norway maple is capable of carrying on the manufacture of sugar when the light intensity is only $\frac{1}{55}$ of the total daylight, whereas cherry is incapable of performing this function if the intensity falls below $\frac{1}{3}$ of the total sunlight. In other words, Norway maple has the ability to endure shade.

If a plant is grown under conditions in which light is insufficient, it shows certain distinctive characters. For example, the color of the foliage is pale green and often sickly, the number of leaves is decreased, there is a scanty development of roots, the growth is more succulent, that is, less woody tissue is developed,

FIG. 129.—Morning (right), noon (center), and evening (left) positions of the same sunflower plant, showing response to the stimulus of light.

the stems are long and spindling, and the plant may fail to bloom and produce fruit. If nursery trees are planted too close, so that there is not sufficient light, they tend to grow long and slender and to have a weak root system. It must be remembered that the vigor of a root system depends primarily upon the food brought to it from the leaves. A decrease in the leaf surface brought about by too close planting is equivalent to a decrease in the food-manufacturing surface.

Sometimes advantage is taken of the response of the plant to decreased light brought on by close planting. For example, flax grown for fiber is planted in a closer stand than when grown for seed. The close stand induces the development of long, slender

stems, which yield fiber of high quality. Also, in growing sorghums and corn for fodder, or for ensilage, where a large amount of succulent growth is desired, the plants are grown close together. Tobacco plants are often grown in the shade of tents, which condition makes a larger and thinner leaf with less vascular tissue. The leaf is thus improved for wrapper purposes.

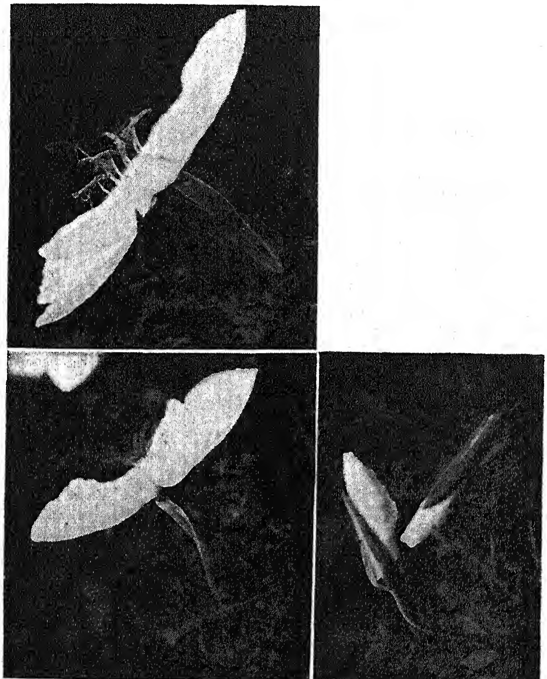

FIG. 130.—The evening-primrose opens its flowers in late afternoon or early evening. The illustration shows three stages in the opening of the flowers.

In general, light of medium intensity promotes vegetative growth, whereas intense light favors the development of reproductive structures. In the northeastern states, where cloudy days are frequent during the growing season, there are splendid yields of potatoes, carrots, turnips, and other crops which are grown for their vegetative structures. On the other hand, the

principal seed-producing regions are found in the western and middlewestern states where the percentage of sunshine during the year is high and the light intensity is relatively great.

Blanching is a process in which the plant is prevented from becoming green by growing it in the dark. To produce blanched (white) asparagus, for example, the plants are banked or ridged up with soil, so that the "spears" must make an additional growth of 4 to 10 inches before they come to light. The shoots that develop in the soil are, of course, whitish. The blanching of celery is accomplished by placing boards, paper, or earth about the stalks to exclude light. The heads of cauliflower are blanched by bringing the outer leaves up over the head and tying them, thus excluding light.

FIG. 131.—Above, celery before blanching is green and not at all like the celery we see in the market. Below, celery in the process of blanching, soil is packed around the leafstalks to exclude the light. The portions of the leaves that are covered lose their chlorophyll and the later leaves develop without chlorophyll.

The intensity of light to which a plant is exposed may be increased by pruning and by a thin stand. One of the objects in pruning trees is to allow light to reach the center of the tree.

The use of artificial light to supplement natural daylight and thus bring about the forcing of plants has been the object of much experimentation. Vegetables such as lettuce and radishes, kept under a strong arc light during a part of the night, become ready for the market from 10 to 14 days earlier than those exposed to normal light duration. Other kinds of artificial light have been used in forcing plants, among them the ordinary carbon incandescent electric light, acetylene light, that of the Welsbach burner. Although artificial light is effective in forcing certain vegetables and flowers, its use is not usually attended with commercial gain, on account of the cost of the light.

Exercise 114. Shade and sun plants. Make a list of shade-demanding plants and of sun-demanding plants. Refer to the catalogs of nurserymen.

Exercise 115. Extraction of the chlorophyll from leaves, and the effect of light on chlorophyll. Place the leaves from which chlorophyll is to be extracted in a flask and add water. Boil for a minute. Replace the water with 80 per cent alcohol and continue to heat on a water bath. **Keep the alcohol vapors out of range of the flame.** When the chlorophyll is extracted, filter the solution. Place a portion of the solution in the direct sunlight, and an equal portion in a dark cupboard. After 30 minutes compare the color of the two solutions. What is the influence of light upon chlorophyll?

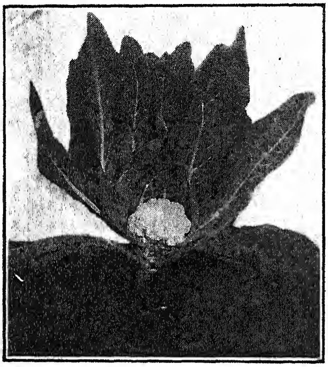

FIG. 132.—A cauliflower head. In the process of blanching cauliflower, the broad, long leaves are tied about the head, excluding the light and thus preventing the head from becoming discolored.

The quality of light. The white light that shines upon the leaf is composed of a number of different rays, which vary in their effect upon plant growth. The visible spectrum, so beautifully shown in the rainbow, is composed of red, orange, yellow, green, blue, and violet light. Beyond the visible red are invisible rays known as infra-red; and beyond the visible violet are rays of light, invisible to the eye, known as ultra-violet. It has been demonstrated that the red rays of light are the most effective in sugar manufacture, and that the green, blue, and violet rays are the least useful of all in this process. Ultra-violet rays of light have an injurious effect upon plants.

Problem 4. What is the relation of plants to the soil?

The soil is the environment of roots. It is in the soil that plants are anchored—in fact, frequently half or more of the ordinary plant body develops within the soil; it is from the soil that a plant absorbs water and mineral nutrients; most perennial plants store considerable quantities of reserve food in organs (roots or rootstocks) which are in the soil.

The soil environment of a plant is very complex. It is more complex than the air. In its effects upon plants we must consider the soil from the three different standpoints; **physical, chemical, biological.**

The chief physical properties of a soil are **texture** and **structure.** **Soil texture** refers to the **size** of the particles which compose a soil mass. As a rule, we distinguish three general kinds of soils as to texture, namely, sandy soils (coarse), loam soils (medium), and clay soils (fine).

Exercise 116. Kinds of soil. Secure three kinds of soil: sandy, loam, and clay. Shake an equal quantity of each in an equal amount of water, using the same kind of receptacle for each mixture. Set in a place where they will not be disturbed. Compare as to the time required for the soil particles to settle out, and for the liquid above the soil to become clear. What is your conclusion regarding the relative sizes of the particles in the different kinds of soil?

Soil structure refers to the **arrangement** or **grouping** of the soil particles. A sandy soil is usually of simple structure, in that the separate particles are much alike, and function separately. On the other hand, a clay soil may be very complex in its structure, in that it may consist of soil granules of many different sizes, held together by glue-like colloidal material. Loam soils are usually regarded as having excellent structure. By this we mean that loam soils are not only porous, but they also hold moisture.

As far as the plant is concerned, the soil is the source of most of the many chemical elements which enter into the plant's composition. Throughout the ages, the rocks of the earth have slowly become fragmented and decomposed to form, along with decaying plant and animal material, the soil. Hence, most soils contain a mixture of both mineral matter and organic matter. We apply the term **humus** to the organic portion of the soil. Humus improves the physical condition of the soil, making of it a better medium for plant growth. We have learned that **all substances which enter the roots must be in solution.** Examination of the liquid portion of a soil shows that it consists almost entirely of water, carrying in solution many different kinds of mineral salts such as nitrates, phosphates, sulphates, etc. The mineral salts in the soil solution, together with carbon dioxide and

water, are the raw materials from which the plant manufactures foods.

The soil as a medium is not wholly inert and lifeless. It is the home of countless micro-organisms, including bacteria, fungi, and protozoa. Bacteria and fungi, particularly, are indispensable in that they are responsible for the processes of decay of organic matter in the soil. Earthworms also play an important rôle in certain soils by aiding in maintaining its tilth.

Water in the soil. All the water taken in by ordinary land plants is obtained from the soil and is absorbed by the roots. All substances which enter the plant must do so in solution, and the solvent is water.

What are the chief conditions which influence the intake of water from a soil? These are as follows: (1) available water in the soil; (2) power of soil to deliver water; (3) extent of the root system; (4) temperature of the soil water; and (5) concentration of the soil solution.

It is a well-known fact that, of the total amount of water in the soil, not all is available for plant growth. If we allow a plant to grow in a soil until it undergoes wilting, to the extent that it will not revive until water is added to the soil, we find that considerable water is still left in the soil. This is water that the plant can not get readily, and hence the plant shows distress. There is water in the soil, but the plant is unable to remove it and utilize it readily for growth. Hence, as far as the plant is concerned, the soil is dry. The percentage of water left in a soil at the time the plant undergoes permanent wilting is spoken of as **permanent wilting percentage.** This permanent wilting is not the same as temporary wilting which frequently takes place when the air is very dry.

The amount of water available for growth varies with the soil. A plant can reduce the water content of a sandy soil to a lower point than it can reduce that of a clay soil. That is, when a plant growing in a sandy loam soil has used all the water it can for growth purposes, the percentage left in the soil is smaller than that left in a clay soil under similar conditions.

For example, after a plant growing in a sandy loam soil has used all the water it can, without permanently wilting, there is

left in that soil but 8.3 per cent water. On the other hand, the same plant growing in a clay loam wilts at a moisture content of 13.6 per cent. Looking at this in another way, a sandy loam having 15 per cent total water would be much "wetter," as far as the plant is concerned, than a clay loam with 16 per cent total water. For the plant growing in a sandy loam with 15 per cent total water can reduce it to 7.8 or 9 per cent; the same plant growing in a clay loam would wilt when the water content was reduced to only 13.6 per cent.

The above facts emphasize the need of knowing not only how much the total water in a soil is, but also how much of it is available for the growth of the plant. Most soils whose moisture content corresponds to the permanent wilting percentage are in a perceptibly dry condition and would be judged by anyone to be in need of water.

But there are other considerations. For a long while it was thought that the greater drought resistance of one plant as compared with another was due to the greater ability of that plant to absorb water from the soil. It has been demonstrated that different plants growing in a similar soil and under similar conditions have approximately the same permanent wilting percentage, in other words, that they reduce the percentage of water to about the same figures. The ability of a plant to resist drought apparently does not depend upon its power to extract water from a soil.

Power of soil to deliver water. If moisture is absorbed by root hairs from the adjacent soil particles at a very rapid rate, as on hot, dry days, it may not move from remote soil layers rapidly enough to supply that lost. It is clear that under this circumstance the soil immediately surrounding the root hairs will become too dry to give up more moisture. Water moves from soil particle to soil particle more rapidly in some soils than in others. The finer the soil, the slower are all water movements through it, but the extent of the movement may be greater.

Extent of the root system. The character of the root systems of plants varies widely. There are root systems (1) that penetrate deeply in the soil; and (2) those that are confined to the surface layers. Some plants do not suffer from drought, because of their

ability to send their roots into the deeper and moister layers of soil. Such a plant is alfalfa. If, on the other hand, the soil is shallow and the rainfall slight, the plants with a shallow root system may be somewhat more successful than deep-rooted sorts, on account of their ability to take advantage of the water that comes to the soil in the form of occasional light showers. It must be remembered that the depth of the root system is an inherited character of the plant, and is independent, to some extent at least, of external conditions. Root development, however, will not take place in a dry soil. Name five plants that have a shallow root system, and five that have a deep root system.

Temperature of the soil water. The rate of absorption is lowered by a decrease in the soil temperature. A plant may wilt in a soil saturated with water if the temperature of the soil sinks below a certain degree. In cold, dry climates winter killing may be the result of a cold soil, which slows up absorption, accompanied by a high transpiration rate. It is believed that in winter killing the plant is as frequently killed by direct drying as by actual freezing.

Concentration of the soil solution. Water passes from the soil through the living membrane of the root-hair cells into the plant. This process of water intake goes on as long as the total concentration of the cell sap is greater than the total concentration of the soil solution surrounding the root hairs. Other things being equal, the greater the concentration of the cell sap as compared with that of the soil solution, the more rapid the water intake. As the concentration of the soil solution approaches that of the cell sap, the rate of absorption slows down. Plants growing in an **"alkali" soil** are exposed to a soil solution of high concentration. Hence absorption is retarded. There may be plenty of water present in the soil, but the plant gets it with difficulty, on account of the high concentration of the soil solution. Name five alkali plants.

Likewise, bog plants are growing in a medium which retards water intake. This may be due sometimes to the high concentration of bog waters, but more often to toxic substances in the soil, which hinder root development. Name five bog plants.

The temperature of the soil. We just pointed out that the soil

temperature influences the rate of absorption by the roots; absorption is retarded or inhibited at low temperatures. Soil temperature also affects the growth of roots, the germination of seeds, and the various activities of soil organisms.

The soil temperature is by no means always the same as the temperature of the air above it. It may be lower or higher than the air temperature. Numerous factors affect the temperature of a soil; chief of these are as follows:

1. Air temperatures. Changes in the air temperature above a soil result in changes of the soil temperature. The fluctuations near the surface are almost parallel to those of the air, but at deeper layers the variations correspond to a lesser degree. The daily temperature change in bare, fallow soil extends to between 12 and 24 inches from the surface.

2. Exposure. By exposure is meant direction of slope. A north exposure, for example, faces north. The effect of exposure is much more marked at high altitudes than at low elevations. This greater effect is a direct result of the increased rate of radiation at high altitudes. The intensity of sunlight is distinctly affected by exposure and also by degree of slope. A given area of soil or plant surface that is at right angles to the direction of the rays of light will receive much more heat than one upon which the sun's rays fall obliquely, for under the latter condition the rays are spread out over a larger area than when they fall perpendicularly. If we assume the intensity of sunlight to be 100 when it strikes a surface at right angles, its intensity when striking that surface at an angle of 70° will be approximately 98.5; at an angle of 60°, 96.5; and at an angle of 10°, 33.4. Light intensity has its effect upon both air and surface temperatures, which indirectly affect the amount of moisture in the soil and the relative humidity over the soil. The differences between the native vegetation on adjacent north and south exposures is so conspicuous in the mountainous sections as to attract the attention of the most unobservant person. In a valley that trends east and west the slope exposed to the south has a much greater total effective heat during the year than the northerly exposure across the valley. The greater light intensity on the south exposure results in not only a warmer, but also a drier, habitat than that on the neighboring north

exposure. A south exposure receives the greatest total heat during the day, the east the next greatest, then the west, and the north exposure least of all. On which exposure will plants bloom earliest in the spring?

3. Living cover. A crop shades the ground and tends to prevent the soil from warming up. A bare soil warms up more quickly and cools off more rapidly than one covered with vegetation.

4. Non-living cover (snow and mulch). It is well known that a snow covering prevents rapid changes in the temperature of the soil. The temperature of soil under snow is higher than that of soil unprotected.

The temperature of a cultivated soil fluctuates to a less degree than that of an uncultivated soil. This is probably due to the poor heat-conducting power of the mulch formed on the surface of the cultivated soil.

A non-living vegetative cover, such as a straw mulch, prevents rapid changes in the soil temperature. It has a cooling effect in the summer and a warming effect in the winter. In the winter the dead vegetative covering acts as a poor heat-conducting medium, which prevents a rapid loss of heat from the soil; and it tends to keep the cold air currents from coming in contact with the soil. It is common practice to place straw mulches over such low-growing plants as strawberries. Why?

5. Moisture. A wet soil is usually a cool soil, whereas a dry soil is usually a warm one. Some of the heat absorbed by a soil is used in evaporating the water in it. A wet soil will absorb more heat than a dry one. Even a light shower will lower the temperature of the surface soil to a considerable degree. Not only does it directly cool the soil by its addition, but, as stated, evaporation also lowers the temperature.

6. Color. Dark soils absorb heat more readily than light-colored ones, and consequently heat up more rapidly.

7. Physical nature of the soil. A coarse soil does not retain water readily, consequently it warms up rapidly. On the other hand, a fine-grained soil, like clay or loam, holds water well and as a result warms up slowly. It is customary to speak of coarse soils as "warm or early," and of the fine-grained soils as "cold or late." Compact soils conduct heat more rapidly than loose ones.

This means that a compact soil will heat up quickly and cool off just as readily.

8. Manures. The general effect of applying manures to a soil is to raise its temperature. In one experiment it was noted that 20 tons of manure applied to an acre increased its soil temperature 5° F.

The air of the soil. The soil is porous. The pore spaces are filled with air and water. A moderately dry soil contains much air in its pores. A very wet soil contains less air than the same soil in a drier condition, for part of the space which would be occupied by water in the wet soil is occupied by air in the drier soil. In a water-soaked soil there is practically no air save that which is dissolved in water. It is well known that most ordinary plants can not thrive for long in a water-soaked soil, for there is an inadequate supply of oxygen.

The composition of the soil air is quite different from that of the ordinary atmosphere. Soil air is richer in carbon dioxide than that of the atmosphere. This is due to the fact that the roots and micro-organisms are absorbing oxygen and giving off carbon dioxide.

What is the rôle of air in the soil? The living cells of the roots must have oxygen in order to respire. A scarcity of oxygen retards root-hair development and the absorption of water and of mineral salts. Seeds must have oxygen in order to germinate. Moreover, most of the bacteria and fungi and other living things of the soil require oxygen, and these have an indirect effect upon green plants growing in the soil.

Mineral nutrients of the soil. The water of the soil carries in a dissolved form many different mineral salts, the so-called mineral nutrients. Many of these constitute raw materials used in the manufacture of food. They furnish to the plant such essential elements as nitrogen, potassium, phosphorus, sulphur, calcium, and iron. The soil solution also carries various gases, chiefly carbon dioxide and oxygen, in addition to the mineral salts.

The nutrient relations of plants are as different as are their bodily form and structure. There are plants such as blueberries which are intolerant of calcareous soils. We speak of plants which are "heavy feeders" and make great demands upon the

soil. Tobacco is such a plant. Other plants are "light feeders" and do not draw heavily upon the chemicals in the soil.

When plants are analyzed chemically we see readily that they have taken varying quantities of the different mineral nutrients from the soil, even when growing on the same soil. They make different demands upon the mineral elements in the soil. It must not be thought, however, that wheat, for example, growing in different kinds of soils and under varied climatic conditions, would take the same amounts or relative proportions of the different elements. We must consider averages based upon the chemical analyses of crop plants made in many laboratories. For example, a wheat crop yielding 30 bushels of grain and 1.6 tons of straw contains on the average 51.6 pounds of nitrogen, 8.6 pounds of phosphorus, 27.5 pounds of potassium, and 5 pounds of calcium. A 200-bushel yield of Irish potatoes removes, on the average, from the soil 42 pounds of nitrogen, 6.3 pounds of phosphorus, 53 pounds of potassium, and 55 pounds of calcium. A 15-ton crop of sugar beets takes from the soil 78 pounds of nitrogen, 10.5 pounds of phosphorus, 79.5 pounds of potassium, and 8 pounds of calcium. Thus we see that crops vary in their demands upon the different principal elements in the soil. Note in the figures above, for example, that a crop of wheat requires very much less potassium than a crop of potatoes or of sugar beets, but it requires more nitrogen than potatoes.

A harvest of fruit from an orchard removes a certain amount of mineral elements, to which must be added those used in the making of leaves, stems, and roots. For example, the fruit only of a 100-barrel apple crop will remove from the soil on the average about 13.8 pounds of nitrogen, 2 pounds of phosphorus, 14.5 pounds of potassium, and 1 pound of calcium.

In the growth of plants for special purposes, man has attempted to find the nutrient conditions which will give him maximum production. He has learned that an abundance of water and of nitrates in proportion to potash makes for succulency in the plant, vegetative growth, and scant fruit production. On the other hand, if the supply of nitrogen is withheld to a degree and potash in the soil is relatively more available, fruit production is stimulated. It is well known that tomatoes on a soil excessively rich in nitrogen

"go to vine" and produce little fruit. In certain wheat-growing sections it has been shown that an excess of available nitrogen over potash in the soil gives a flinty, hard grain; and that a starchy, mealy, and soft grain results if there is a lack of nitrogen and a relatively good supply of potash. Too much nitrogen, on the other hand, produces a tall plant, with a weak stem, which lodges easily.

Fertile and infertile soils. In common understanding a "fertile soil" is one which will produce. A soil to be productive or fertile must have, of course, (1) the proper amount of water; (2) a supply of free oxygen; (3) a supply of available mineral elements; (4) no harmful agents such as fungous diseases, weeds, insect pests, alkalies, acids, and toxins; (5) certain beneficial bacteria and other fungi; and (6) a physical condition which is favorable to seed germination and root development.

In a more restricted sense, "fertility" or "infertility" has reference to the mineral nutrients, the so-called plant foods of the soil.

Man's control of the nutrient relation is largely concerned with making up a deficiency of some mineral nutrient brought about by the growth of plants. When a soil becomes infertile, that is, incapable of producing a normal yield, the infertility is usually due to a lack of either nitrogen, potassium, or phosphorus. These are the elements most commonly deficient in soils. The other essential elements are seldom lacking. Thus it is that most artificial fertilizers contain one or more of these elements. Barnyard manure contains all the elements necessary to increase a soil's productive power. Of course, it is true that manures of different farm animals differ in their chemical composition. Name several common commercial fertilizers.

However, there is reason to believe that infertility of soil is not always due to a lack of essential mineral nutrients, although this is probably the most important cause. It appears that some soils with an abundance of mineral nutrients are non-productive because of toxic substances in them. There is evidence that, if a given crop is grown year after year on the same piece of soil, there accumulate in that soil toxic substances which are deleterious to the growth of that plant. Thus it would seem that one of the advan-

tages of crop rotation is the counteraction of these toxic substances by the new crop. Further, it is believed that the value of adding manure in a case of this kind is in counteracting the toxic substances in the soil rather than in adding mineral nutrients which are deficient.

In some instances, an unproductive soil may be due to organisms in the soil which attack the roots of the plant and cause disease. If one kind of crop is grown year after year on the same land, the soil fungi which prey upon that plant accumulate and the soil becomes non-productive, even though mineral nutrients are abundant.

Living organisms in the soil. The upper layers of the soil teem with living organisms, chiefly bacteria. In addition to bacteria there are various fungi, algae, protozoa, and worms. It is difficult to overemphasize the tremendous importance of bacteria in the economy of nature. The groups of soil bacteria particularly beneficial are those which bring about the decay of organic matter and those which fix nitrogen. At this point the student should review the discussion of soil organisms on pages 94–97, and throughout the following section reference should be made to Fig. 37.

Bacteria in relation to soil fertility. Contrary to popular opinion, not all bacteria are harmful. In fact, many of them are absolutely essential in maintaining the life of the earth. Chief of these indispensable bacteria are those which bring about decay, breaking down complex organic substances such as proteins, fats, and carbohydrates into simpler substances that can be used again as raw materials in the manufacture of foods by green plants. Their presence and activity in the soil are necessary to maintain soil fertility.

Ammonifying and nitrifying bacteria. Nitrogen is an essential element in plant growth. It is a constituent of the living material (protoplasm) itself. It is one of the principal components of both plant and animal proteins, and of many other chemical compounds in living bodies. It is well known that soil infertility is often due to a scarcity of available nitrogen, and that one of the principal ingredients of fertilizers is nitrogen in some form.

Nitrogen occurs in the atmosphere as a gas. About 80 per

cent of the air is nitrogen. However, green plants are not able to absorb the atmospheric nitrogen and use it in the building of foods. Although nitrogen gas, along with carbon dioxide and oxygen, passes through the pores (stomata) of the leaf, it is not utilized by the plant in the free, gaseous form.

Nitrogen occurs in combination with many other chemical elements. For example, ammonia (NH_3) is a combination of nitrogen and hydrogen, 1 part of nitrogen to 3 parts of hydrogen. Ammonia is a chemical compound of nitrogen and hydrogen. The nitrogen in this compound is not free, but is bound to hydrogen. In other words, the nitrogen is **fixed**. Another very common chemical compound is sodium nitrate or Chile saltpeter. This compound contains sodium, nitrogen, and oxygen in the proportion of 1 part of sodium, 1 part of nitrogen, and 3 parts of oxygen ($NaNO_3$).

A great many mineral salts contain nitrogen, but of these, sodium nitrate, and its close relative, potassium nitrate, are the most important as sources of nitrogen for green plants. The nitrogen in nitrates is spoken of as **nitrate nitrogen**.

As has been stated, nitrogen is one of the most important elements in plant and animal proteins. Manures are rich in nitrogen, for they contain plant and animal products. But the nitrogen in manures, or in any plant and animal refuse, is chiefly in a protein compound. It is **protein nitrogen**. It is significant that green plants can not use directly the nitrogen of proteins. It is necessary that the relatively complex protein compounds be broken down into simpler compounds of nitrogen, and that finally nitrates be formed. In other words, protein nitrogen must be changed to nitrate nitrogen. In all soils, under proper conditions, the nitrogen-containing compounds of manure are being changed to nitrates. This change is dependent upon the activity of **three** different kinds of bacteria. If these soil bacteria are not present, or if conditions are unsuitable for their growth and multiplication, manure does not decompose, and nitrate nitrogen is not formed.

In the first place, the proteins of manure are decomposed through the activity of a group of bacteria known as **ammonifying bacteria**, and among the various decomposition products is ammonia, which of course contains nitrogen. The first step then is the

change of protein nitrogen to ammonia nitrogen. Following this, another distinct group of bacteria changes **ammonia nitrogen to nitrite nitrogen,** and still another group of bacteria changes the **nitrites to nitrates.** The two groups of bacteria which change ammonia to nitrates are called **nitrifying bacteria.** In the three chemical changes brought about through the activity of soil bacteria, the unavailable protein nitrogen has been changed to the available nitrate nitrogen. In this last form the nitrogen is readily absorbed by green plants, and utilized by them in the building of the proteins of their own bodies.

It is seen that the soil teems with bacteria which are extremely beneficial and essential. It is clear that conditions in the soil must be such as to promote their growth and development. These organisms require a good supply of oxygen, a certain amount of water and warmth, and usually the presence of calcium or magnesium compounds.

Nitrogen Fixation. It was stated in a preceding paragraph that green plants can not use free nitrogen gas of the air. The same is true of most plants and of all animals. However, a very few bacteria and other fungi are able to take free nitrogen and to build it into the nitrogenous compounds of their bodies. Such organisms have the power of **nitrogen fixation.**

There are two principal groups of nitrogen-fixing organisms: (1) those which live on the roots of other plants, chiefly legumes, and (2) those which live without any association with the roots of higher plants.

Legume bacteria cause the development of tubercles or nodules on roots. These tubercles or nodules vary considerably in size. Examination of a tubercle shows it to be composed of the swollen tissue of the host, in which are millions of the nitrogen-fixing bacteria. Examine the roots of a number of different legumes for the presence of bacterial nodules.

How the growing of legumes improves soils. It has been found that a clover plant, for example, secures about two-thirds of its nitrogen from the bacteria in the nodules, and one-third from the soil. Further, it is known that about two-thirds of the total nitrogen in the clover plant is in the tops (hay) and that the remainder is in the roots. Thus, it is seen that, when a crop of

hay is taken from the land, there is removed an amount of nitrogen about equal to that coming from the air, and fixed by nodule bacteria. The roots remain in the soil and in time decay, the nitrogen they contain being returned to the soil. It will be clear, from the figures given above, that if a clover crop is to enrich the soil in nitrogen, it must either be plowed under, or fed to animals whose manure, which of course contains nitrogen, is returned to the soil. If the hay if sold off the farm, the growth of the legume has not enriched the soil in nitrogen.

Denitrification. In addition to the ammonifying, nitrifying, and nitrogen-fixing bacteria of soils, still another group plays a part in influencing soil fertility. This is the denitrifying bacteria which change ammonia nitrogen to free atmospheric nitrogen. Such bacteria are undesirable from the soil fertility standpoint, for they take nitrogen from the soil. Denitrifying bacteria are most active in soils that are poorly drained and hence not well aerated, and in soils which contain large quantities of unfermented organic matters.

The nitrogen cycle in nature. As has been stated, nitrogen occurs in many different forms in nature: in the free gaseous form; as a part of inorganic compounds, such as ammonia, nitrites, and nitrates; and as a part of organic matter, either in the non-living or living form. In the processes of nature, nitrogen is constantly being changed from one form to another. Through the activity of denitrifying bacteria, and in electric discharges, nitrogen compounds are being broken down and nitrogen set free. The free nitrogen of the air in turn is taken by certain bacteria and changed into proteins and other compounds of plants containing nitrogen. The nitrogenous compounds of plants are changed to ammonia, the ammonia to nitrites, and the nitrites to nitrates. The nitrates are then used to rebuild plant proteins. Or plants are consumed by animals and the nitrogen of plants is used in the making of the nitrogenous compounds of animals. The organic nitrogenous substances excreted by animals and the dead bodies of animals undergo decomposition, as a result of which nitrogenous compounds break down, liberating ammonia, which is in turn changed to nitrites, and nitrites in turn to nitrates. It is worthy of repetition to say that the processes of decomposition, of nitrification, of nitrogen

fixation, and of denitrification are brought about through the action of bacteria.

QUESTIONS

1. Why is there so little humus in the soils of arid and semi-arid regions?
2. Compare the three common types of soil as to their ability to hold water.
3. In canyons, gulches, or ravines which run east and west observe the differences in the plant life on north and south exposures. Explain.
4. How does man artificially increase the temperature of the air about plants?
5. Describe the way to construct a hot bed; a cold frame.
6. Give the physical characters of a warm or early soil; a cold or late soil.
7. Mention three ways of raising the temperature of a cold or late soil.
8. Why are crusted soils injurious to plants growing therein?
9. Give five reasons for crop rotation.

Problem 5. What is the relation of plants to the air?

The entire plant is surrounded by the gases of the atmosphere. This includes the roots, which are surrounded by the air of the soil. The air that surrounds the plant supplies it with oxygen, necessary for respiration. All parts of the green plant absorb oxygen rather directly from the air which is about them; and in the presence of light, green plant tissue also absorbs carbon dioxide. Even the roots obtain oxygen from the soil air immediately surrounding them.

In animals, the oxygen used in respiration, and the carbon dioxide eliminated in this process, are conveyed to and from the cells by the blood. In plants there is nothing corresponding to the blood stream. The sap of a plant does not carry appreciable quantities of these gases. In plants there is, however, an extensive system of air spaces between the cells, which communicate directly with the exterior through the stomata in the leaves, and through loose, open groups of cells (**lenticels**) in the bark. Consequently, the cells are surrounded by the gases of the atmosphere, and these can move inward and outward through the moist cell walls. Certain types of cell walls will permit oxygen and carbon dioxide to diffuse through them, even when they are dry.

In most crop plants the system of air spaces in the plant is not extensive or continuous enough to permit ready movement of air

through the leaves and stems to the roots. Roots and root hairs absorb oxygen from the air which is present in the soil between the soil particles. In other words, the rapidly growing and active root hairs on a root which is several feet beneath the soil surface obtain oxygen for respiration chiefly from the soil air immediately surrounding them. There is no system of ventilating tubes which is adequate to convey sufficient oxygen from above ground to these subterranean structures except in aquatic and semi-aquatic plants. The normal growth and functioning of the root hairs, and consequently the absorption of water and mineral salts from the soil—

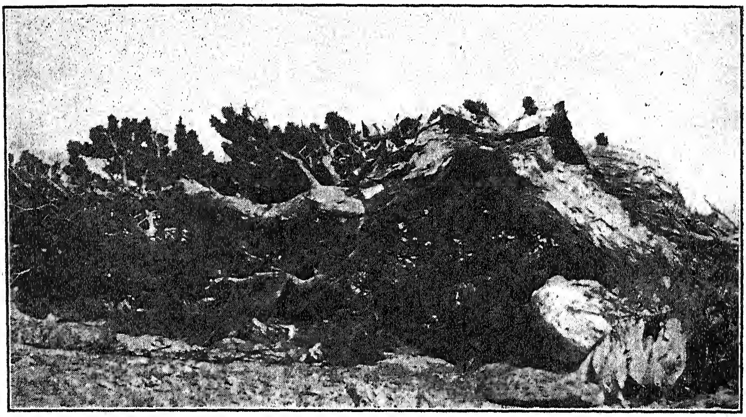

Fig. 133.—Wind timber on the slopes of Long's Peak, Colorado. On windswept slopes of high mountains, near timber line, where the winds are prevailingly from one direction, the trees are often prostrate, and with twisted branches. (Photograph furnished by R. J. Pool.)

and in fact the health of the entire plant body—all depend upon an adequate supply of oxygen to the soil. It is known that the oxygen requirement of roots varies with the temperature of the soil. At a high soil temperature, the amount of oxygen necessary to give a normal rate of growth is greater than that required at a low soil temperature. Be that as it may, the fact remains that in all our treatments of the soil we should keep in mind the requirement—an ample and constant supply of oxygen in reach of the root hairs. The soil needs ventilation. It must be porous enough

to permit the free movement of air through it. If it is crusted on top, owing to irrigation or rain, the free movement of air is interfered with, and the roots of plants are likely to suffer from a lack of oxygen. If the soil is extremely wet, the air supply is also diminished.

Air Movement. We are familiar with the fact that clothes on the line dry much more quickly on a windy day than on a quiet day. The rate of evaporation, or loss of water vapor, is increased by wind movement. Wind is one of the several important factors which influence the loss of water vapor from the surfaces of plants. It does this by constantly removing from the surface of the plant the film or extremely thin layer of moist air which accumulates there, thus making way for the more free diffusion of water vapor outward from the air spaces within the leaf.

Wind also influences the form of trees. Witness trees that grow at timber line on wind-swept mountain slopes, or along the sea coast. Here, as a result of winds which blow prevailingly in one direction, the trees often have most of the branches coming off the leeward side. This is due to the drying effect of the winds which prevent buds from developing on the windward side. Moreover, as a result of the continued mechanical strain, such trees frequently lean strongly leeward.

Wind and Reproduction. Wind is of service in the reproduction of plants in that it transports pollen and disperses seeds.

Problem 6. What is the interrelation of plants and animals?

There is an intimate interrelation between animal life and plant life. We have already called attention to the fact that the soil is traversed by many species of animals: earthworms, insect larvae, ants, etc. These animals are dependent upon plants for their food, and the animals in turn, especially earthworms, grind up plant remains into small pieces, mix their food with mineral particles, bury soil fragments in the soil, and by burrowing in the soil render it more porous. Thus, these animals render physical and chemical changes in the soil which are beneficial.

One of the most intimate interrelations between animals and plants is seen in the insects which carry pollen. The flowers

provide the insects with nectar and pollen; the insects carry the pollen and thus contribute to the plant's reproduction. Thus, the insect and the plants are mutually helpful.

So completely dependent are some plants upon some one species of insect for pollination that they can not exist without that insect. Some time ago Australians decided that red clover would be a splendid crop plant for their soil and climate, so they imported some. But they could not get it to set any seed until they imported the red clover's special pollinator, the bumblebee.

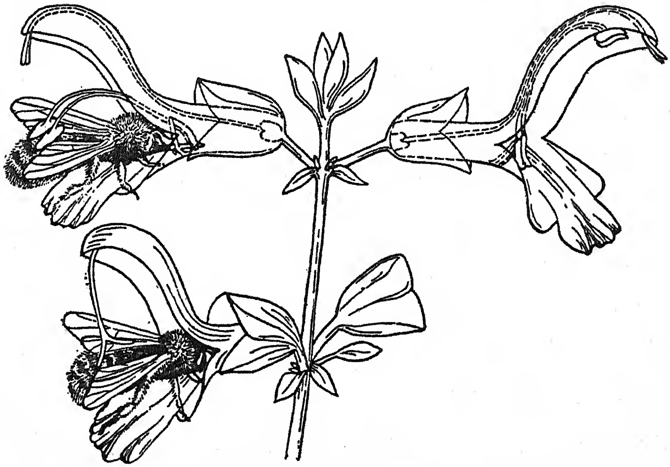

FIG. 134.—The anthers of the meadow sage form a lever which the insect works himself. The anther lever is illustrated in the two upper flowers. After the anthers have withered the stigma grows down into a position where the insect must rub his back, covered with pollen from visits to younger sage flowers, against it, as shown in the lower left flower. (From Robbins and Pearson, in Sex in the Plant World.)

Orchids are usually pollinated by moths. There is a famous case of an orchid, the Madagascar orchid, which produces its nectar in a spur nearly a foot long. On the strength of the existence of this flower, a naturalist predicted that a moth would be discovered with a proboscis that long, although none was known at the time. Surely enough, such a moth was soon found frequenting the habitat of the Madagascar orchid.

Very rarely, the insect seeks the flower, not to sip the nectar, but for a place to lay its egg. A remarkable instance occurs in the flowers of *Yucca,* a common desert plant. Reproduction in *Yucca* depends upon the assistance of the *Pronuba* moth. In turn the larvae of the moth gain their livelihood from the *Yucca.* The female moth with the aid of her special tentacles collects from a number of flowers a mass of pollen. Then, while still clinging to her cargo, she pierces the ovary of a *Yucca* flower with her long egg-depositor and lays an egg within the ovary tissue. This duty having been performed, she proceeds promptly to the stigma of the flower and presses the pollen ball into the stigma. This process of collecting pollen, of depositing an egg in the ovary of a flower, and of pounding the pollen into its stigma is repeated time and time again by the insect. *Yucca* ovules are fertilized; thus does the plant profit. Moth larvae hatch within the ovary and live upon some of the developing seeds; thus does the insect profit. It is no exaggeration to say that the very existence of *Yucca* plants depends upon the strange habits of *Pronuba* moths, and likewise the continuity of the moth upon this earth is dependent upon the *Yucca.*

FIG. 135.—The Pronuba moth "hand pollinates" the Yucca flower. Each time she lays an egg in the yucca ovary, she makes sure that yucca seeds will be growing to feed her larvae when they hatch. In the upper flower a moth is collecting pollen; in the lower flower a moth is laying an egg; in the central flower a moth is placing a ball of pollen on the stigma. The pod shows holes through which the Pronuba offspring have escaped. (From Robbins and Pearson, in Sex in the Plant World.)

The wasp "psen" which Aristotle saw fly out of a fig thousands of years ago, was born and raised there, and was on its way to crawl into another fig to lay its eggs and die, like all the females of its kind ever since that day and long before. A fig is a peculiar sort of flower-

bearing stem which has grown long and fleshy at the periphery until it completely encloses the whole cluster of very small staminate and pistillate flowers. The *Blastophaga* wasp goes through its entire life history from grub to adult within the fig. The males never see the outside world; they fertilize the females and die. But the females crawl out of the fig. By the time they get out they are well dusted with pollen from the male fig flowers they have had to crawl over. Now they enter other figs in quest of female flowers in which to lay their eggs. The wasps do not know it, but they can not get their eggs into the ovaries of ordinary female flowers. However, the fig also bears

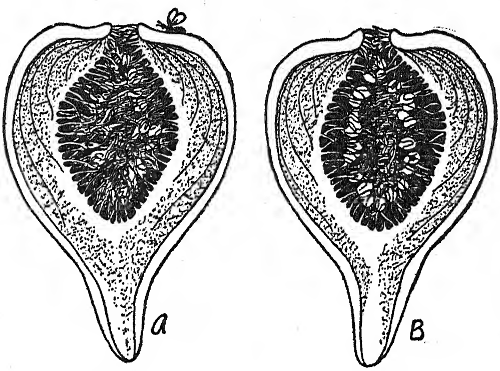

Fig. 136.—Pollination of the fig. A, median lengthwise section of a fig showing fertile female flowers; note the female fig wasp near the opening, also another one inside. B, similar section of a fig showing gall flowers. (From Robbins, in Botany of Crop Plants.)

a peculiar deformed type of female flower in which they can lay their eggs, and they finally do. But in the meantime, while they have been trying out the good female flowers, they have scattered pollen plentifully over the stigmas, and the fig seeds will set and the fig race be perpetuated.

The seeds and fruits of many plants are a source of food for animals. Unwittingly, often the seeds are scattered by animals, and thus does the plant profit. Many birds eat fleshy fruits, the seeds either being regurgitated or passing through their alimentary tracts uninjured. Such seeds are quite likely to be deposited

under conditions suitable to their germination. The seeds or fruits of some plants are provided with devices which enable them to adhere to the hairs of animals and thus be disseminated to new soil areas. As examples we cite the beards of certain grasses, the spines of the sand-bur, and the hooks or barbs of the cocklebur. Squirrels carry away and hide nuts, some of which may find favorable conditions for their germination.

A few plants have means for securing animal food. The leaves of Venus' fly-trap, sundew, pitcher plants, and bladderwort are so constructed as to capture insects, which are finally used as food by the plant.

The character and distribution of plants in the world have been profoundly influenced by man. He has domesticated many wild plants; he has hybridized them and carried them to all parts of the world, far from their original homes. He has removed forests, plowed the plains and prairies, and introduced grazing animals, thus greatly modifying the natural plant covering.

REFERENCE

Productive Soils, by W. W. Weir, published by J. B. Lippincott Company, Philadelphia, 1920. 395 pages, 234 illustrations. Definite and practical information concerning soils and profitable crop production. It treats of soil and its origin, soils from a chemical point of view, soil and plant relations, crop production, factors determining soil fertility and principles of soil fertility and soil management.

UNIT VII

HOW PLANTS ARE FITTED TO THE CONDITIONS OF THEIR SURROUNDINGS

We speak of the surroundings of plants as their **environment.** The study of plants in relation to the environment in which they are living is known as **plant ecology.** Different factors of the environment which affect plants are water, light, air, soil, temperature, and living things, both plants and animals. Any condition in the surroundings which causes a change in a plant is known as a **stimulus.** The effect that is caused by a stimulus is a **response. Only living things can be affected by a stimulus.** There can be no response in a lifeless object.

Most seed plants have both a soil environment and an air environment. That is, they have their " feet " in the soil, and their " heads " in the air. The roots grow in the soil and they are related by structure in a way that fits them to the conditions of the soil environment. The factors of the soil environment are water, temperature, soil salts in solution, solid mineral substances, soil air, and soil organisms. In a way, we may also consider gravity as a factor of the soil environment. It differs from the other factors, however, in that it is nearly constant all over the surface of the earth, while the others are extremely variable. The roots are fitted to absorb water and salts from the soil solution and to anchor the plant in the solid earth materials.

There may be substances in the soil which are injurious to plants. Such substances as acids and alkali may be present in the soil solution in concentrations which make it impossible for plant processes, as absorption, to go on in a normal way. Plant species differ in their ability to maintain life and grow under severe conditions. When a plant is resistant to an unfavorable factor of the environment, we say the plant is **tolerant** of that

particular condition. Thus we have acid-tolerant plants, drought-tolerant plants, and alkali-tolerant plants.

Plant breeders have produced, by hybridization and selection, varieties of cultivated plants which are tolerant of conditions under which other varieties of the same genus would fail. Most varieties of alfalfa winter-kill in the severe winters of our northern states. Grimm alfalfa, developed from a cross between common alfalfa and yellow-flowered alfalfa, is tolerant of the low temperatures of the northern winters and is grown successfully in these states.

As we look about and see plants growing in nature, we note that some species of plants are found flourishing under conditions of extreme dryness, as lichens and mosses on the face of a rock cliff. We see others wholly or partially submersed in the water of ponds and lakes, as *Elodea* and water lily. Other plants with peculiar structural features can survive the conditions of the extremely dry habitat (we speak of the place in which a plant is growing as its **habitat**); likewise, only plants fitted to such an environment could live in water. In each type of situation we are apt to find a number of species living together, each fitted, by structure, to the particular habitat. Plants which are not tolerant of the conditions of a habitat are not found in the group. Thus we find plants of the same species and those of similar species of plants regularly living together in plant societies as, for example, the pond society and the desert society.

When we study the fitness of plants in any situation, we are impressed with the fact that the two rôles of plants are **nutrition** and **reproduction**. A plant must be able to provide food for itself, but it must also provide for the future of the species by some means of reproduction. Many plants have the ability to reproduce rapidly by vegetative means, as the strawberry by stolons or runners, the horseradish by roots, the quack grass by rhizomes, and the Jerusalem artichoke by tubers. Seed plants, in general, must be fitted by structure for the processes of pollination, formation of gametes, fertilization, and subsequent development of the seed, in which is tucked away the young plant, together with a food supply sufficient to give it the necessary start in life when planted. Various structures in connection with fruits, as wings,

hooks, and barbs, provide aid in dispersal of seeds by wind or animals.

Problem 1. To what kinds of stimuli do plants respond?

When we consider the relation of plants to their surroundings we must realize that they are living things, their active parts being composed of the living material which we call protoplasm. We can study the properties of protoplasm, but we know very little about the reasons for its power to move, to grow, or to be affected by stimuli. Scientists have learned that living things behave as they do because of two major factors, both depending upon the nature of the living stuff, protoplasm. First, **they inherit certain characteristics from their parents**; and second, **they are influenced by their surroundings.**

Tomato plants always have the same general characteristics of stem, leaf, and fruit. We can always recognize the plant as tomato. However, when plants of tomato grown in the sun are compared with plants grown in the shade, marked differences are found. The shade plants are apt to be tall, have slender stems and thin leaves, and bear little or no fruit; sun plants of tomato on the same type of soil will be strong and sturdy and set an abundance of fine fruit. The characteristics which enable one to recognize the plants as tomato are inherited; those which vary with change in habitat are the result of reactions to conditions in the surroundings.

How do green plants respond to light? If you have tried to grow a plant by a window of your room, you have noted that the stem gradually became curved toward the light. You probably noted also that the petioles of the leaves twisted in such a manner as to bring the leaf into a plane transverse to the direction of the rays of light. A maple tree growing in an open field where light comes from all sides develops a low, symmetrical, and dense top with branches extending from the trunk almost to the base, whereas a tree of the same species in the thick forest grows a tall and straight stem having branches only at the top where light penetrates. See Figs. 197, 152.

Exercise 117. What effect does light have upon the form of the plant? Grow in darkness a pot of bean plants for two weeks or longer. Compare

general shape of plants, size of stem, size of leaves, color, etc., with the same features of plants growing in normal light for the same length of time. Answer the question of the exercise by means of diagrams.

Exercise 118. What effect does gravity have upon the primary root of the plant? Plant corn grains which have been soaked over night, with tip of grain down, slightly below the surface in moist sawdust or sand. Remove the grains when the root is 1/4 inch in length and transfer to a moist chamber prepared as follows: Fasten four cork stoppers to the bottom of a dish by means of melted paraffin. Pack into the bottom of the dish about the stoppers absorbent material, such as moss, or bits of newspaper, filling up and leveling off after wetting the material until it is even with the tops of the attached corks. Place sheets of blotting paper over all, cutting to extend slightly up along the edges of the dish. Fasten four sprouted grains of corn through the blotting paper into the corks by means of pins so that the roots point in different directions. Cut a piece of glass to fit as a cover and fasten in place with adhesive tape. Support on edge in a shallow dish holding water to supply moisture which will rise in the absorbent material by capillarity. Make a drawing of the moist chamber as set up, showing definitely the position of the roots at first. In what direction did gravity pull on the roots while the seeds were germinating in the sawdust? In how many different directions is gravity pulling on the four roots now? In so far as the seedlings are concerned, you have changed the direction of the pull of gravity. Examine after a day to determine the direction taken by the root tips in the meantime. Make a drawing showing the seedlings as they appear now and compare with the drawing made when the moist chamber was set up. What has been the response to gravity in this experiment?

Exercise 119. What effect has gravity upon the stem of the plant? Support a vigorously growing potted plant in a horizontal position in a dark room and examine after 24 hours. What change has taken place in the stems of the plant? By changing the position of the stem you have changed the direction in which the pull of gravity is applied to it. What is the response in this case? What is the stimulus? Compare the stimulus of Exercise 118 with the stimulus in this experiment. Compare the response of Exercise 118 with the response in this experiment. In a single connected statement, answer the question at the beginning of this exercise.

It is evident from the results of our experiments that the root and the stem are affected by gravity in quite different ways. In some way which has not been explained, gravity causes the taproot of a plant to grow downward and the main stem to grow upward. These reactions are beneficial to the plant as they take the root system down into the soil where there is water together with nutrient soil salts. They take the shoot up into the air where the leaves are exposed to the necessary sunlight and where the flowers and fruits are in a position which favors the processes of pollination and seed dispersal. Give two reasons why the main stem of a tree usually grows upward. Give two reasons why the branches of a tree usually grow outward from the main stem.

Tropisms. Curvatures in plant organs, such as those caused by light and gravity, are known as **tropisms,** and the organ of the plant which is affected is said to be **tropic.** Tropisms due to the stimulus of light are **phototropisms,** and those due to gravity are **geotropisms.** The primary root is **positively geotropic** and **negatively phototropic,** while the main stem is **negatively geotropic** and **positively phototropic.** Other responses of plants are those caused by the stimuli of chemicals, **chemotropism**; those caused by water, **hydrotropism**; and those caused by contact, **thigmotropism.**

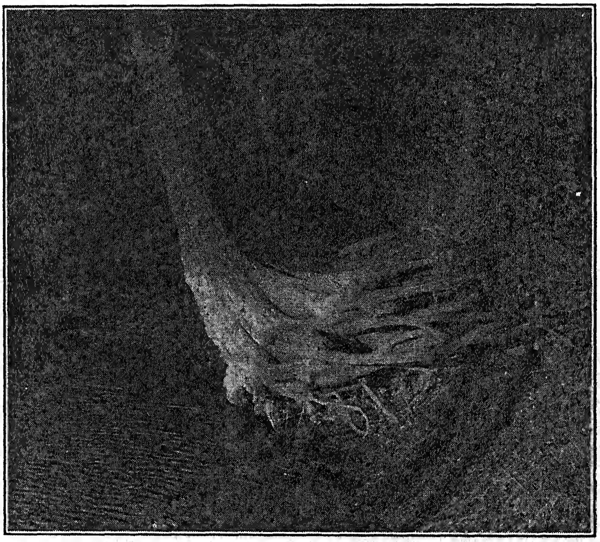

FIG. 137.—Explain what you see in this picture. What response determined the behavior of the roots of the tree?

Roots grow towards available soil salts and water and around solid objects with which they come in contact. It is sometimes necessary to cut down willow and poplar trees which are near tile drains because of the tendency of the roots of those trees to enter the drains through the cracks between the separate tiles and fill up the tiles with masses of fibrous roots, completely stopping the flow of water. It is a well-known fact that an

occasional thorough soaking of a lawn will produce a deeper root system of the grass than frequent light sprinkling. How can you explain these facts in terms of the foregoing discussion?

It should be remembered that the whole plant, above and below the surface of the soil, is in a complex environment, subject to the application of a number of forces. The form and nature of the plant, including root, main stem, branches, and leaves, is governed by all these forces acting at the same time. On the side of a cliff the taproot of a young seedling may take a horizontal direction into a crevice which holds moisture, reaction to moisture being greater in this case than reaction to gravity. Secondary roots are not affected by gravity in the same way as primary roots. Their course extends out from the main root approximately perpendicular to the line of pull of gravity. Although the reasons for this are not understood, it is recognized as a definite advantage to the plant as it enables the root system to reach all parts of the soil within the radius represented by the length of the longest lateral roots. The farmer, in cultivating his growing corn, digs the soil deeply at first to prepare loose soil for the spreading secondary roots; then later he uses shallow cultivation to avoid injury to the lateral roots while he prevents the growth of weeds and provides a mulch of fine soil to hold the moisture.

The leaves of most plants are **dia-phototropic.** By this we mean that the petiole twists in such a manner as to place the blade in a plane at right angles to the incident light rays. At the same time the leaves are placed in such a position with reference to each other that a minimum of shading is secured, so that in looking down upon the plant one sees a **mosaic** of leaves. The mosaic is so complete in some trees, as the Norway maple, that scarcely a speck of sunlight can be seen in the shade of the tree. The mosaic is well shown also in the **rosette** of mullein, dandelion, or evening primrose. It is also shown in an interesting way by Boston ivy on a wall where the light reaches the plant from one side only. Mosaics are shown in Figs. 125, 126.

Give one case in which an animal reacts to light and two cases in which a plant reacts to light. Compare the reaction of an animal to light with the way a plant reacts to the same stimulus. Why does a plant react differently from an animal?

Problem 2. How are plants related by structure to the water supply?

With respect to water there are many different types of plant habitats in nature. They range from those types in which there is an abundance of water, as in ponds and marshes, to those in which there is a scarcity of water, as on the bark of trees, on the surface of rocks, or in desert sands. In these different situations we find plants related to the water supply in different ways according to the conditions in the individual habitat. Plants of the same species are not found in all these situations. A plant species has inherited qualities which fit it, in general, to live in a certain type of habitat. There is a certain condition, as to water supply, in which the plants of a species are most likely to succeed. There is, however, frequently a rather wide range of habitats in which the plants of the same species will grow. Most plants have the ability to react immediately to changed conditions in a way that is an advantage to the plant. Plants growing where water is scarce are usually structurally different from plants of the same species growing where the water supply is sufficient. Likewise, plants growing in bright sunlight are different from plants growing in the shade. It is a well-known fact that lettuce grown early in the season while the water supply is ample and the days are neither too hot nor too long is apt to be crisp and delicious, while that from a later sowing which reaches development during the hot, dry weather of mid-summer will be tough and bitter.

How are plants fitted for absorption? As we have seen, the younger parts of the roots are covered with a fuzzy growth of root hairs. These make possible rapid absorption of water by increasing the area of suitable absorbing surface. Water roots are normally without root hairs, but most land plants have the root hairs exceptionally well developed.

The roots of tropical orchids are peculiarly fitted for water absorption. These plants are known as **epiphytes**, since they live upon other plants from which they derive no nutrient materials. Their roots do not touch soil, and the whole plant is suspended in an air habitat. The air surrounding the roots is usually quite moist, but this has only the indirect effect upon the water supply of reducing the evaporation from the plant. The only water avail-

able to epiphytes is that which wets the absorbing surface in the form of rain or dew. A spongy outer layer of roots of orchids, known as the **velamen**, takes up the water by capillarity in the same way that blotting paper takes up water. From the velamen the water passes inward from cell to cell by diffusion until it enters the conductive system of the root.

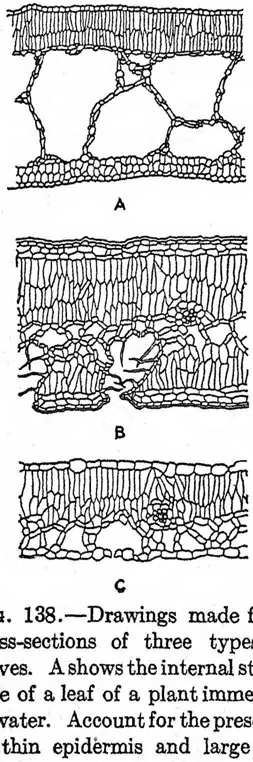

FIG. 138.—Drawings made from cross-sections of three types of leaves. A shows the internal structure of a leaf of a plant immersed in water. Account for the presence of thin epidermis and large air spaces, and the absence of stomata. Note in B the heavy cuticle, thick epidermis, compact internal structure, and location of the stomata in depression and protection by hairs. Explain how these features fit the plant to living under desert conditions. C shows the section of a leaf grown under conditions of moisture intermediate between those of A and B. Explain presence of the thin epidermis, moderately compact internal structure, and exposed stoma.

The seed plant, Spanish moss (*Tillandsia*), which hangs from the branches of trees in great festoons in the southern states, has no roots. Absorption is accomplished by special structures on the leaves which take in water that wets the plants as rain or dew.

Carnivorous plants. The word carnivorous comes from the two Latin words, *carnis* (flesh), and *vorare* (to devour). We are not accustomed to think of anything but animals as using flesh for food. A few plants, however, have the power of digesting and absorbing animal substances. Examples of this group of plants are, the pitcher plants, sundew, and Venus' fly-trap, all living in swamps and bogs. Plants living in these situations have poorly developed root systems, and as a result water absorption is restricted. This condition also hinders the absorption of nitrogen salts in sufficient amount to supply the needs of the plant for raw materials. Besides, there is very

little mineral material in the waters of the peat bog, and this places an additional difficulty in the way of the plant's securing mineral salts. In some way, which is not well understood, these plants, in the course of their evolution, have developed the carnivorous habit.

In pitcher plants the modified leaves form pitcher-shaped vessels which catch rain water as it falls and hold it indefinitely. The leaf pitcher is smooth inside and is provided with a lip which has hairs over its surface pointing downward toward the interior of the vessel. The pitcher, partly filled with rain water, forms a trap for beetles and other insects that happen to get into it. Because of the peculiar structure of the vessel, the hapless insect is

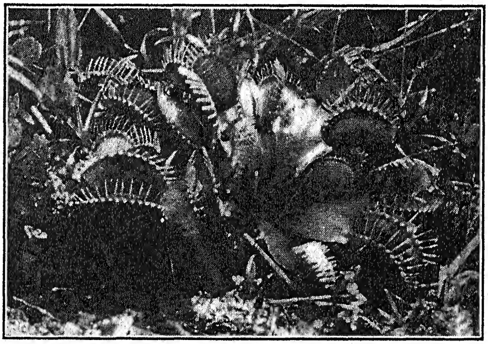

FIG. 139.—The leaves of Venus' fly trap are adapted to the capture and digestion of insects.

unable to crawl up the sides, and as a result, it finally dies. In the case of the pitcher plant shown in Fig. 140, substances resulting from the decomposition of the insects are absorbed by the cells of the pitcher as organic food for the plant. Like other green plants, the pitcher plant is able to make food for its own use, but it also seems able to supplement this supply with that which it secures through the carnivorous habit.

The sundews grow in situations similar to those in which pitcher plants are found. Each leaf has a definite petiole which holds a circular leaf blade. Numerous hair-like projections extend vertically upward from the upper surface of the blade, the ones at the

edge being longer than those at the center. At the end of each projection there is a glistening droplet of a viscid substance which resembles dew in appearance. Insects, attracted by the sparkling droplets and wine-red color of the leaves, alight and stick fast to the hairs. This contact stimulates the leaf, which reacts by rolling the edges inward, thus bringing other hairs in contact with the insect and entangling it still more. The trapped insect dies, its body is digested by enzymes secreted by the hairs, and the organic food thus made available serves to supplement the supply which the sundew is able to make.

Partial parasites. Some plants which are dependent upon other plants contain chlorophyll and can make a part or all of their foods. Mistletoe is a plant with chlorophyll which is a widely distributed parasite on trees. The sticky seeds adhere to the branches of trees where they germinate. The young plants send their complex absorptive structures down into the tissues of the branch until they reach the conductive structures. Here they derive from the host raw materials, including water and mineral salts, and also a part of their food supply. Since these plants are somewhat dependent but do not obtain all their foods from the host, they have been called partial parasites.

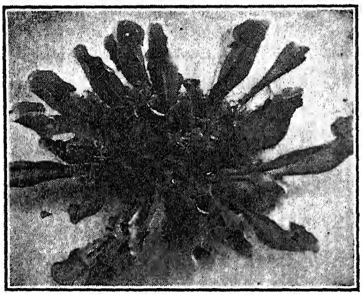

FIG. 140.—The pitcher plant, a carnivorous plant.

Ability to withstand drying. You have probably noticed, as you walked in the woods, a slight coating on the north side of many trees, grayish green in dry weather and bright green during rainy periods. This is an alga known as *Protococcus*, the Indian compass plant, so called because the presence of masses of this plant on trees could always be relied upon by Indians in the woods as a guide to direction. In dry weather the cells are inactive. When rain comes they rapidly absorb water, begin to grow and multiply, and because of the large number of active cells they appear as a light-green coating on the bark. Many of the lichens

and mosses show this same ability to retain life during periods of extreme drying, to revive quickly when wet, and resume their normal life activities. The resurrection fern (*Polypodium polypodioides*) may grow from the crevices of rocks or as an epiphyte on trees. It has the usual fern characteristics when moisture is sufficient, but as the drought approaches, the leaves wither and curl and the plant appears to be without life. When water again becomes available, the leaves uncurl and immediately take on a bright green, and the plant begins a new period of activity. The Mexican resurrection plant (*Selaginella*), sold in stores as a novelty, may remain dormant for months in a dried condition and still retain life. (See Fig. 147.)

Exercise 120. Collect pieces of bark to which dried lichens are attached and pieces of bark with a coating of *Protococcus*. Moisten, place in a shallow dish with a little water, and cover with a bell jar or inverted battery jar. What change do you note in the appearance of the plants? Place in the light and observe for several days. What do you conclude as to the ability of the plants to revive after drought?

Water loss in plants. Under ordinary conditions, a green plant is continuously losing water. In fact, water loss is one of the most serious of the problems connected with the growth of plants. Water plants which are submersed are not subject to danger from loss of water. In most swamp plants which have their roots in a soil saturated with water, excessive loss by evaporation is readily made good by increased absorption. In bog plants, however, and the plants of salt marshes, which have water in abundance, absorption is difficult, and hence excessive water loss is destructive. The question is one of water balance. The amount of water lost by the plant through evaporation together with that used in food manufacture must not exceed the amount of water taken into the plant by absorption. In habitats where the water supply is deficient or where absorption is difficult, specialized structures are necessary to prevent excessive water loss.

Why do plants lose water? Since water loss incurs danger to the plant, why should there be water loss? Suppose the plant were so well protected that there would be little or no loss of water to the outside. The deciduous tree in winter condition is almost completely impervious to water. At this time, however, the tree is

comparatively inactive. The different plant processes are practically at a standstill. The plant could not continue to live in that condition indefinitely. If you will recall the features of leaf structure which make food synthesis possible, you will remember that exchange of gases with the outside is made possible by openings, usually in the lower epidermis, the stomata. See Fig. 28. These holes in the epidermis of the leaf are an absolute necessity since carbon dioxide must enter the leaf as raw material for food synthesis, and oxygen must escape as a by-product of the same process. Besides, some oxygen must be available inside the leaf at all times to be used by the plant in the process of respiration. When the leaf is active the stomata are open and the water which evaporates from the moist cell surfaces into the intercellular spaces in the spongy tissue constantly diffuses into the atmosphere surrounding the leaf as long as the humidity of the air outside the leaf is less than that of the air inside. If the air surrounding the leaf is dry, evaporation and diffusion from the active leaf take place rapidly and water loss is great. If the air outside the leaf is saturated with water vapor, as it frequently is in the tropics, there is little water loss from the leaf. Thus, while water loss may be a menace to the plant under dry conditions, it can not be prevented if the plant is to function. The success of plants in many situations depends upon their ability to develop protective structures which guard against excessive loss of water. The loss of water from plants by evaporation is called **transpiration.**

How is the water supply of plants conserved? There is nothing in the environment of plants more variable than the water supply. It is an exceptional season if we do not have to sprinkle our lawns many times to keep the grass from drying up. At times, some means of conserving water is necessary to save the life of the plant. It may be necessary, even, for a plant to drop its leaves in midsummer during a severe drought. In general, plants or parts of plants which are exposed to dangers of excessive drying develop protective structures which tend to prevent conditions that might be fatal to the plant. Sun plants are apt to be protected more than shade plants, and even in the same tree, the exposed upper leaves are more protected than the shaded lower ones. In the older leaf the outer walls are usually thickened by a deposit of a fatty sub-

stance known as **cutin**. This aids in protecting the leaf against excessive water loss. Cutinization of the epidermis of the apple and other fruits tends to hold the water inside. Broad-leaved evergreens, as holly and magnolia, show especially heavy cutin deposits which protect the plants during the colder seasons when absorption of water from the soil is more difficult and excessive loss from leaves might be fatal. The leaves of the sedums (live-forever) and those of many other plants are coated with a layer of wax, known as "bloom," which prevents the escape of water. In spraying cabbage plants for protection against insect pests, soap must be added to the spray solution to dissolve the wax on the leaves. Otherwise, the spray solution rolls off the waxy leaf in large drops without wetting it and the insects are able to eat the leaf without getting any of the poison.

Leaves of mullein, *Shepherdia*, and other plants are covered with hairs which prevent free movement of air currents and thus reduce evaporation. This condition seems also to reduce the absorption of heat by the leaf and in this way indirectly prevents water loss.

There is a decided tendency toward **leaf reduction** in plants exposed to dangers of excessive transpiration. In the cactus, food synthesis occurs exclusively in the stem; the only leaves of the plant are small structures which appear on very young stems and are soon lost. In some of the euphorbias, natives of Africa, which are occasionally seen in our conservatories, there are true functioning leaves which are dropped at the approach of drought, a new crop appearing when rains bring about conditions which are more favorable. Frequently, in conditions of severe drought, our deciduous trees lose many of their leaves, even in mid-summer. This is a protection against more severe injury which might result if transpiration were not checked.

Many plants which live in regions subject to drought conditions, as the aloes and cacti of the arid regions of the southwestern part of the United States, are fitted to these conditions by having **thick, succulent leaves** or **stems**. A large amount of water is stored in these structures when water is available. The plant is able to draw upon this store for use in maintaining the normal plant processes when there is a scarcity of water in the soil. Purslane, a common weed of field and garden, has a succulent stem and succu-

lent leaves which may hold water sufficient to keep the plant alive for days, even when uprooted. You may dig a purslane plant and cut it into pieces, and if these pieces lie on moist soil the various fragments will send out adventitious roots and produce a large number of separate purslane plants. This characteristic of water-retention is taken advantage of by florists in propagating certain varieties of begonia. Triangular pieces of the leaf, each containing a portion of a prominent vein, are set in sand. In this position they remain succulent and fresh until they have had time to develop roots and a bud, drawing upon the supply of food and water stored in the succulent leaf portion. After the adventitious roots and young shoot are well developed, the plants are transferred to pots of good soil where they soon become established and develop into sturdy begonia plants.

In some plants, as in *Aloe*, the water-storage tissue is below the green tissues; in others, as in begonia, the water-storage tissue consists of the lower cells of a thickened epidermis. Stonecrop, which belongs to the former class, thrives on the scant water supply afforded by the thin layers of soil in the depressions of rock outcrops. The different sedums (live-forever) are used extensively in rock gardens and at other places for carpeting very dry, sandy, or rocky places in the open sun.

Water absorption and water retention are especially difficult in plants living in salt marshes and on alkali soils where the salts in the soil solution are highly concentrated. Plants in these situations must have a sap with a total concentration of solutes (solids dissolved) greater than that of the soil solution. In other words, the concentration of water particles in the soil must be greater than the concentration of water particles in the plant sap, otherwise water can not enter the root hairs of the plant by diffusion. This same principle seems, also, to be of importance in explaining the resistance of many plants to drought conditions. Protective structures of leaf and stem are important in preventing excessive water loss by transpiration, but the condition of concentration of cell sap which makes possible the absorption of water from comparatively dry soil is probably of no less importance.

What type of roots are plants likely to have if they are growing in a region where there are occasional light rains? What type of

stem are these plants likely to have? What types of roots and stem is a plant likely to have in a region where there is regularly a period of fairly heavy rainfall alternating with a long rainless season?

Problem 3. Why are certain types of plants found living together?

What are plant communities? It is a source of interest to be able to study the vegetation from what we may call a bird's-eye view of the landscape. From such a study one of the first things that we discover is that vegetation is grouped according to habi-

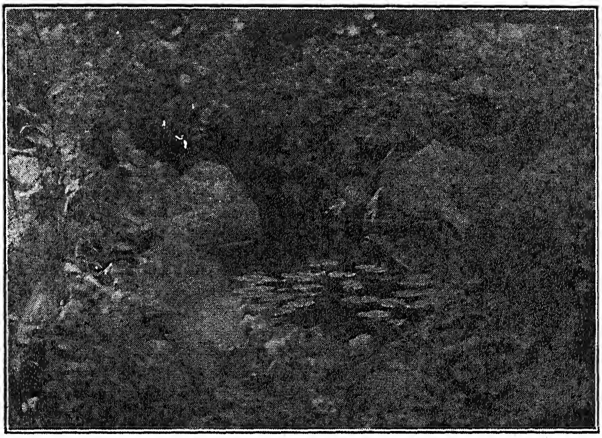

FIG. 141.—Lily pond in a backyard. What different types of plant surroundings are represented in this rock garden and lily pond?

tats. There are ponds, swamps, flood-plains, sand hills, uplands, deserts, each habitat having a particular type of vegetation. A closer study reveals the fact that not only are certain species of plants found regularly in a certain type of habitat, but, in general, all the species found in a given type of habitat have many characteristics in common. Botanists have found that the most convenient way to classify plants on the basis of habitat is according to their water relations. Plants found regularly in pond or swamp habitats are called **hydrophytes**; those found regularly in dry situations are known as **xerophytes**. By far the greatest number

of different species are found growing regularly under conditions which may be considered intermediate between those of hydrophytes and xerophytes. Plants which grow best under conditions of moderate water supply are called **mesophytes**. All the plants

FIG. 142.—Mesophytic woods of beech and maple trees carpeted by spring flowers. The soil is rich in humus. It is not wet, but the supply of moisture is usually sufficient during the entire growing season.

of a habitat make up a **plant community**, and, classed on basis of water supply, communities are **hydrophytic**, **xerophytic**, or **mesophytic.**

Where oaks are found growing, one is likely to find hickories along with them. Then there are apt to be shrubs of witch hazel and spice bush, and such herbs as meadow rue and false Solomon's seal. These plants and many others are found growing together regularly in definite plant communities, and in habitats that are similar. Different grasses, rosin weeds, and blazing star are plants of the prairie community; *Sphagnum* moss, pitcher plant, sundew, and cranberry are plants of the bog community; and beech, maple, tulip tree, blood root, and dog-tooth violet are found regularly

FIG. 143.—The prickly pear, a xerophyte. The thick flattened structures are green stems with much water storage tissue.

together in the mesophytic forest. The pioneer settlers of parts of our country were able to select lands which promised to be suitable for certain crops which they desired to grow, by noting the type of plants which the land supported in the uncultivated state. Soil in the eastern part of our country on which was found a good growth of maple, beech, black walnut, and tulip tree was considered ideal, when cleared of trees, for growing crops of corn, wheat, oats, and clover.

Hydrophytic plant communities. Plants growing in ponds and lakes are subject to fewer and less abrupt changes than plants in any other habitat. Temperature is more nearly uniform in water than in air, and the water requirements of the plant are satisfied at all times without any necessity for special provisions for absorption or the prevention of water loss. The plants may be partly floating on the surface, or submersed and rooted, or floating free. Among the plants that are usually submersed are the pond weeds (*Potamogeton*) and water weed (*Elodea*). Some of these frequently become a nuisance in park ponds because of their rapid and profuse growth. Many of the pond plants, as yellow pond lily, reproduce vegetatively by rhizomes in the mud. The exposed surface of floating leaves, as those of water lily, is usually coated with wax which prevents wetting of the surface and filling of the stomata with water. Submersed leaves are finely cut or ribbon-form and for that reason are not easily injured by water currents. Stems of water plants have little mechanical tissue. The plants do not need to support themselves to any great degree since they are held up by the buoyant force of the water. Air passes readily through the vegetative structures of the plant within a system of air chambers and open spaces in the tissues, giving the plant buoyancy and facilitating the exchange of gases

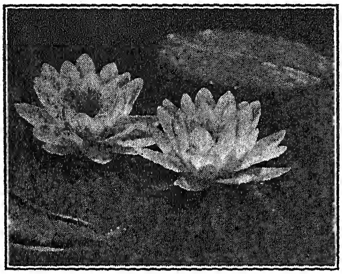

FIG. 144.—Explain why there are no stomata on the under side of a water-lily leaf. Account for the waxy condition of the upper epidermis.

FIG. 145.—The "knees" of cypress. The cypress is an conebearing tree growing in the swamps of southeastern United States. The roots are in very wet soil, and consequently there is not an ample supply of oxygen. The "knees" are growths of spongy tissue sent up from the roots into the air, and through them oxygen passes down to the roots.

in the food-making and other tissues of the plant. Plants of the pond community succeed in their particular habitat because of their special fitness to live submersed, wholly or partly, in water. Young growing wheat or corn plants, if covered by a pond of water after a heavy rain, even if for only a short time, are killed. The wheat and corn plants are not fitted by structure to the conditions of a water habitat. Year after year plants migrate to the water's edge and hundreds of seeds are blown into the water, but still the pond community is limited in species to the comparatively small number which are fitted to the conditions which the pond affords.

Swamp plants are similar to pond plants in some respects, having a reduced root system and prominent air chambers; however, in general characteristics they are more like mesophytes, particularly in leaf thickness, distribution of stomata, in amount and character of green tissue, and in protective structures.

The **peat bog** is a peculiar type of swamp in which there are deposits of varying depth of partly decayed plant matter upon which vegetation is growing. The usual type is the *Sphagnum* bog in which the substratum is mainly dead *Sphagnum* moss. In the early stages the substratum is always saturated with water. Although some plants migrate into the bog from the outside and grow fairly well, in the main the plants of this community are peculiar to the bog, consisting of such species as *Sphagnum*, sundew, cranberry, pitcher plant, dwarf birch, poison sumac, and tamarack. The plants of the bog are characterized by small leathery leaves and sparse root systems. Tamarack trees in the bog have roots only at or near the surface of the soil, but these trees planted in high ground become deep-rooted and show no tendency to remain at the surface. The saturated peat soil is unusual in many respects. The *Sphagnum* deposits are sour, and this has a tendency to prevent the growth of soil bacteria. This condition, along with the absence of oxygen, tends to prevent decay and other necessary soil reactions. Under these circumstances, acids and other toxic substances form in the soil, and there is a scarcity of soil salts in the bog waters. These conditions inhibit root growth and restrict the process of absorption.

It seems odd that plants growing in soil saturated with water should have leaf structures similar to those of plants of dry regions

which serve in preventing excessive water loss. In the light of the foregoing discussion, the need of protective structures of plants growing in bogs is evident. It has been found that tamarack trees and other plants of the bog will grow even better in situations outside the bog under suitable ordinary conditions. Why, then, are they characteristic bog plants? The answer is found in the fact that the bog is highly selective. These plants, being tolerant of bog conditions, grow here because there is less competition. So we have in the bog a plant community made up of species which are able to tolerate the unfavorable conditions of this type of swamp.

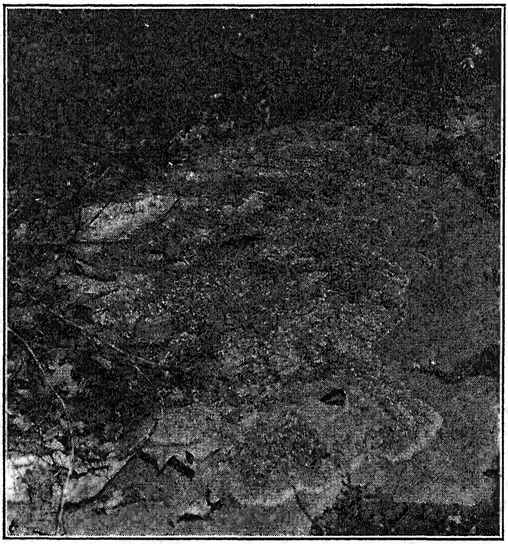

FIG. 146.—Lichens and mosses are among the first plants which are active in the process of transforming rocks into soil.

Xerophytic plant communities. The deserts and dry plains of the southwestern part of the United States offer examples of habitats where water is scarce and plant growth is difficult. Plants must possess special structures to be able to withstand the severe conditions of these habitats. The root system is generally extensive and deep, the sparse, shallow root system of the cactus being a notable exception. The plants contain much water-storage tis-

sue, or a highly developed cuticle, or a wax covering; or a plant may possess more than one or even all of these features which tend to prevent an excess of water consumption and water loss over water intake. Some of these plants either have no leaves, food synthesis being accomplished by modified stem structures, or there may be small leaves, or leaves which are easily dropped during extended drought periods.

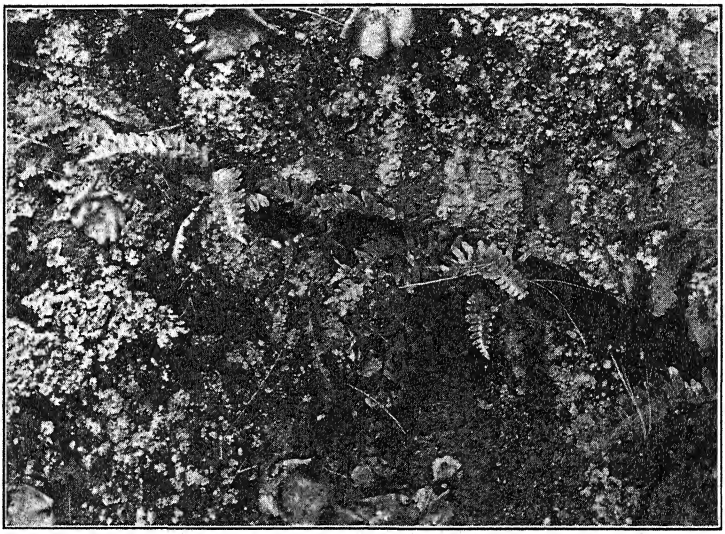

FIG. 147.—Plants that can withstand drying. The lichens growing on this rock face and ferns clinging to the crevice are active during rainy periods. During times of drought they remain in a semi-dormant condition.

Xerophytic plants have had an important part in the making of soil out of solid rock. Lichens and mosses are able to grow on rock surfaces when the rock is moist from rains, sending their absorbing structures (rhizoids) out into contact with the surface. These structures give off carbon dioxide, which with water forms carbonic acid. This slowly dissolves the rock. A part of the dissolved rock becomes raw materials for plants and a part goes back to rock in the form of very fine particles which, with the decaying plant bodies, form soil. As this process goes on, together

with the action of water and frost, more and more soil is added until other plants which migrate into the community can get established, and finally the rock is covered with a layer of soil sufficient to support a rich mesophytic vegetation. As the habitat changed, migrants came into competition with the xerophytes and gradually crowded them out. So, as the plants change the habitat, they bring about conditions suitable for other plants which are better fitted to the new conditions, and the pioneers are eliminated. Here is an example of a plant succession starting in a xerophytic habitat. Under mesophytic climatic conditions this type of succession goes through the various stages from xerophyte to mesophyte.

Fig. 148.—A tree Yucca in the Mohave Desert, California. A typical xerophytic tree.

Mesophytic plant communities. In a mesophytic climate such as the deciduous forest region of the United States, succession is always toward the condition in which the habitat is occupied by mesophytic plants. In the ordinary swamp and bog, development begins in a hydrophytic habitat. As the succession continues through the swamp stage, there is a gradual development of a mesophytic community in which the plants require only a moderate water supply. On dry sand or rock surface where plants survive only with difficulty, plant deposits, as leaves and other vegetative parts, are added year after year, and these organic substances, together with fine sand or clay, form a humus which has the property of retaining moisture. After long periods of time, the habitat, formerly extremely dry, has developed a soil which holds sufficient water to support a mesophytic vegetation consisting of such plants as beech, maple, jack-in-the-pulpit, blood root, and spring beauty. Thus, the types of plant communities

we see today in parts of our landscape which have not been altered by man are the results of changes which have been going on for many thousands of years. Plants fitted to the environment have come, and as the environment changed these have gone and their places have been taken by others in a succession which has culminated in what we see now.

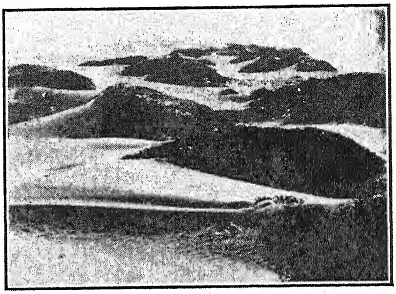

FIG. 149.—Halophytes (salt plants) in the dune succession, Oceano, Calif.

Plant succession. Plants growing in a pond or lake tend to leave deposits which gradually fill up the depression and produce conditions which are unfavorable for the plants themselves. There are usually swamp zones about the pond, and many of the plants in the zone next to the shore push out to the water's edge, and even into the water, by means of the prominent rhizomes which they possess. The swamp plants encroach upon the pond and by their deposits aid in eliminating it. Thus the pond with its typical community of plants gradually disappears and is followed in turn by the different stages of the swamp and finally by a mesophytic forest. As conditions change, plants of the habitat are displaced by migrants which are more suited to the new conditions, and so become established. Thus there is a series of more or less definite stages in the development of a region. The succession of plant communities which results from successive changes in plant habitats we call **plant succession.**

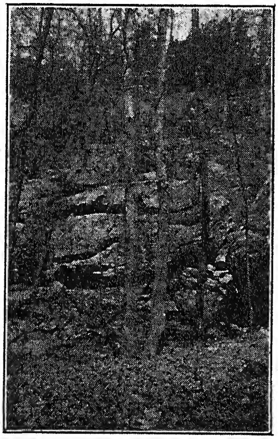

FIG. 150.—Following lichens and mosses on rock materials, first herbs appear, then trees and shrubs. Scene in Southern Illinois.

How has man affected plant succession? When man becomes a pioneer in a new region he cuts down the trees of the forest or he

breaks up the sod of the prairie or drains swamps to prepare the soil for growing his crops. He builds dams which cause streams to overflow their natural banks, causing the flooding of many acres of dry soil. These changes in the habitat of plants result in sudden changes in the different plant communities.

A result of rapid water run-off sometimes brought on by forest destruction is the washing of much of the fertile humus from the hills to the lower grounds and into the streams. The fact that flood-plains and deltas are built up from the humus

FIG. 151.—Trees get a foothold in crevices of the rock and thrive in this difficult habitat.

washed from higher lands accounts for the great fertility of the river lowlands and the increasing infertility of the hills. Thousands of farms in our country have been abandoned because the cultivation of the soil on the lands is no longer profitable.

Burned-over forests and abandoned farm lands represent habitats in which few plants but xerophytes can grow. Plants fitted to these severe conditions gradually come in and there is the beginning of a new succession. Herbs, shrubs, and trees come into the habitat, and these add humus to the soil and hold

it in place. After many generations, if man allows the succession to go on, the final result will be a condition similar to that which man found when he arrived as a pioneer. Alabama, Mississippi, Michigan, Wisconsin, and other states have thousands of square miles of land which is being reforested in this natural manner.

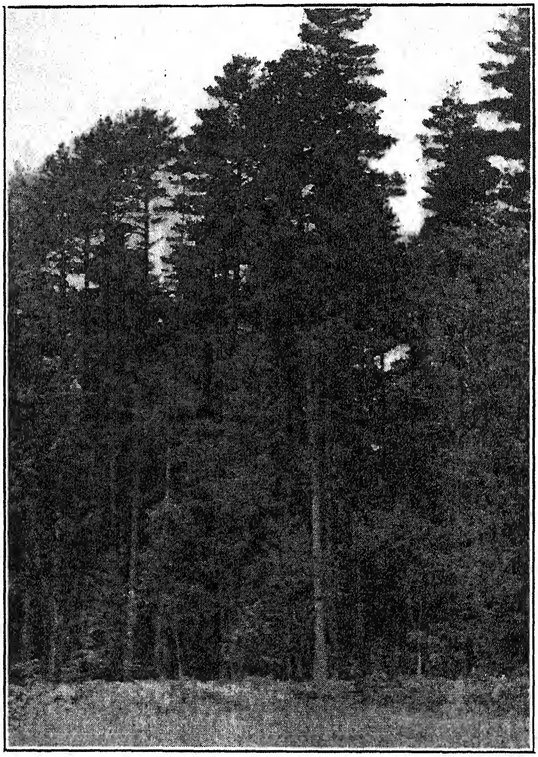

FIG. 152.—A magnificent pine forest in Michigan. Forests similar to this one formerly covered extensive areas in the north central states.

Man is the most destructive of the forces that affect plant succession. Frequently through carelessness he starts a forest fire which sweeps over thousands of acres of territory, leaving destruction of the work of centuries in its wake and changing a mesophytic plant habitat into one in which only xerophytes can dominate.

Statistics for the year 1931 show that forest fires swept over 52,000,000 acres in the United States in that year alone, with a money loss of \$65,968,350. It has been estimated that approximately 50 per cent of forest fires are caused by locomotives, 8 per cent by smokers, 0.1 per cent by camp-fires, and 11 per cent by boys. By proper education and care, man could prevent forest fires, or greatly reduce their number, except those caused by lightning. What factors of the native environment is it sometimes

FIG. 153.—A good stand of hardwood trees at the University of Illinois. Practical forestry is becoming more and more of a necessity.

possible for man to change in a way to increase productivity when he begins to cultivate the soil?

Exercise 121. Field study. How are the plants of a pond fitted to the conditions of the water habitat? If possible, study the conditions and plant life of a pond or lake; if this is not possible, answer as many of the questions as you can by a study of a well-stocked aquarium or lily pond. Note the characteristics of the plants which are submersed, paying attention to character of leaves as to texture, thickness, size, form, and shade of green; to the character of the stem as to size, amount of mechanical tissue, and whether covered by a protective coat of cutin, wax, or cork; and to the roots, if present, noting whether they are water roots or soil roots. If both kinds of

roots are present account for the presence or absence of root hairs on either water or soil roots. How do submersed plants secure carbon dioxide and oxygen? Explain whether cutinization of leaves would be a benefit or hindrance to submersed plants. Explain presence or absence of much mechanical tissue in submersed plants. Try to determine why the plants do not sink to the bottom. Describe features of any plants which you find floating on the surface of the water, as *Riccia* (a liverwort), duckweed, or water hyacinth. What advantage has a floating plant over a submersed plant? What disadvantages to the plant are there in the floating habit? Study rooted plants with floating leaves, as water lily, noting wax coating of the exposed surface.

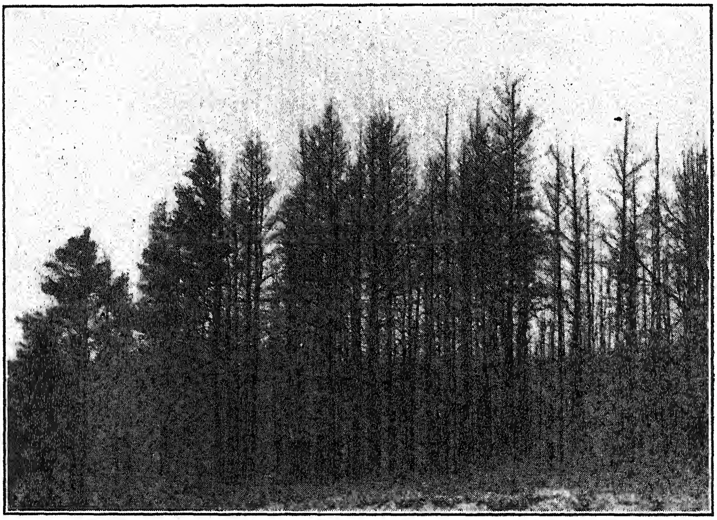

FIG. 154.—Forest fire destruction. Man's carelessness caused the destruction of a fine growth of young timber.

Splash some water over these leaves and try to determine the rôle of the wax. Describe the light exposure of the water lily. Take water plants in closed cans back to the laboratory with you for further study. Write a full account of your field trip, answering the question at the head of the exercise.

Exercise 122. Field study. How are swamp plants fitted to the conditions of the habitat? Visit a swamp at the edge of a pond, if possible. Study emersed plants, as bulrushes, arrow head, and water plantain. Examine the interior of portions of the plants, as stem and leaf petiole. What characteristics have these swamp plants in common with emersed pond plants? Explain. Study the plants of the zones of the swamp seen as one goes out from the pond. These represent stages in the development of the habitat from the hydrophytic to

the mesophytic condition. Note the large number of plants with vertical leaves, as cat tails, reeds, and sedges. What is the advantage of this type of leaf in places where vegetation is dense? Remembering that the soil of the swamp in the earlier stages is saturated with water, how do you account for the fact that the roots of the plants extend in a horizontal direction near the surface, and some even extend upward? In so far as you are able to make this study of the swamp, try to answer the question at the head of this exercise in a clear and concise statement of the results of your investigations.

Exercise 123. Field study. How are plants fitted to the conditions of a xerophytic habitat? Study the plants of any dry habitat, as a dry prairie, sandy hill slope, or railroad embankment. Note the character of the leaves of the plants, as to thickness, texture, color, and size. Break some of the stems. Are they

Fig. 155.—Why are our wild flowers disappearing? Here is one answer.

succulent and brittle, or are they hard and tough? Determine the character of the roots by digging up some of the plants. Describe any tendency to the development of thorns and spines, or hairy leaves, or the rosette habit? Do you find any compass plants, as wild lettuce or rosinweeds? Write a detailed account of your study, giving your opinion as to why the plants which you found were able to become established in this xerophytic habitat.

Exercise 124. Laboratory study of a mesophyte. In our study of plants in previous units, we have considered the mesophyte as our typical plant. It remains for us here only to consider the characteristics of mesophytes which distinguish them from hydrophytes and xerophytes. Select any available mesophytic plant of the greenhouse or garden, as geranium, bean, or four o'clock. Note the character of the leaves as to color, size, thickness, texture, and cutinization. Study Fig. 138, showing sections of the leaves of a hydro-

phyte, of a xerophyte, and of a mesophyte. Compare the structure of the three types of leaves, paying special attention to cuticle, upper and lower epidermis, palisade tissue, spongy tissue, and occurrence of stomata. How do mechanical tissues of the stem of mesophytes compare with those of hydrophytes and with those of xerophytes? Write a summary comparing the features of mesophytes with those of hydrophytes and with those of xerophytes.

Problem 4. How are plants related by structure to the process of pollination?

Pollination has been defined as the transfer of pollen from the anther of a flower to a stigma. The stigma receiving the pollen may be in the same flower with the anther producing the pollen or it may be in another flower. When pollen is transferred from the anther to the stigma of the same flower, the process is called **close pollination.** When close pollination is effected by contact of stigma and anther, it is called **self-pollination.** When the transfer of pollen is from the anther of a flower to the stigma of a flower on another plant, the process is termed **cross-pollination.** A condition intermediate between close-pollination and cross-pollination, in which pollen is carried from a flower to another flower on the same plant, is sometimes classed with cross-pollination but, in reality, it is more nearly related to close pollination.

Most flowers seem to be fitted to the process of cross-pollination. It has been noted that some flowers are especially suited to cross-pollination by certain insects, as red clover by bumblebees. Many other examples of pollination by certain animals may be cited. In connection with this, the student should review the interrelations of plants and animals discussed on pages 238–242. The long bill of the humming-bird easily reaches the nectar at the bottom of the long spurs of the columbine, which is out of reach of the mouth-parts of bees, so the humming-bird is the principal agent in cross-pollination of the columbine. The long proboscis of the hawk moth, hovering before the *Nicotiana* flower, is uncoiled and thrust down into the tube of the corolla, at the base of which there is an abundance of nectar which is used by the moths as food. The relationship between *Nicotiana* and the hawk moth is seen further in the fact that the moths are active only in the evening or at night and they are aided in finding the

flowers by the light color of the corolla and the marked fragrance of the blossoms. On the body and legs of insects are hairs and bristles to which pollen may stick and be carried from flower to flower. Indeed, the relation between the structures of flowers and the structures of insects is so noticeable that biologists believe that flowers and certain insects developed together in their changes in form.

Why do insects visit flowers? It is a well-known fact that many insects secure nectar from flowers, using it for food on the spot, as butterflies moths, and certain flies, while others, as bees,

Fig. 156.—Columbine flower. Only humming birds or butterflies and moths can reach the nectar in the tip of the spurs.

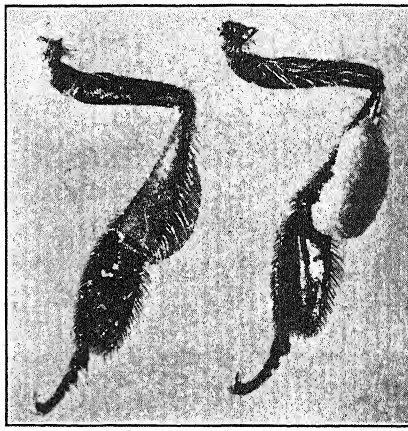

Fig. 157.—The hind legs of the honey bee are well constructed for the collection of pollen. (From California Agricultural Experiment Station Bul. 517.)

lay by a store for future use. Bees collect nectar, not honey, from flowers. This substance, which contains only from 15 to 40 per cent of sugar, is lapped up by the mouth-parts of the bee and transferred to a honey sac near the stomach, in which it is held until the bee reaches the hive. Here the nectar is placed in cells and left until evaporation of water changes it into honey with a very high percentage of sugar. Bees also gather pollen and store it temporarily in cells, to be used later as food, chiefly by the larvae or young bees. Bumblebees and honeybees

are the most efficient pollinators among the insects. This is due partly to their unceasing activity, and partly to their habit of confining their visits on the same trip and on many succeeding trips to flowers of the same species. "White clover" honey as offered by apiarists is produced in the white clover season and may really

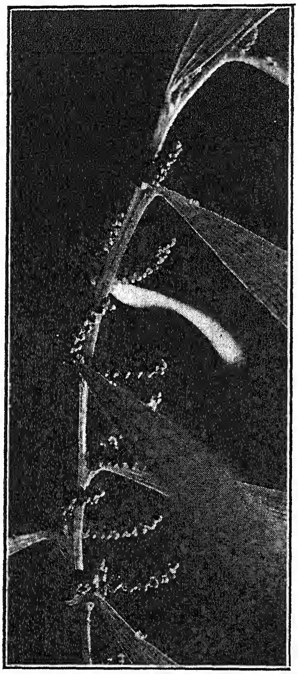

FIG. 158.—Nectar glands sometimes occur on the leaves of certain acacias. These glands appear as small protuberances. (From California Agricultural Experiment Station Circular 62.)

FIG. 159.—Pelican flower (*Aristolochia*), a carrion-scented flower, attracts flies as pollinating agents.

have been made almost exclusively from nectar secured from white clover blossoms.

Nectar is secreted by special structures of the flower known as **nectaries** which are exposed in some flowers and hidden in others. In flowers having exposed nectaries the nectar is usually accessible to flies and other insects without specialized mouth-parts. In

specialized flowers having concealed nectaries, the nectar can be obtained only by insects with mouth-parts modified to form some type of proboscis.

In some flowers, as those of the poppy and nightshade families, there is little or no nectar. Insects visit these flowers only for pollen, which is usually produced in great abundance. In some cases pollinating insects visit flowers for sap, and in others, for protection. Certain flowers, as pelican flower (*Aristolochia grandiflora*) of conservatories, and our native carrion flower (*Smilax herbacea*) attract different species of scavenger flies by an odor resembling that of decaying flesh. These flies may get nothing from the flowers, but serve as efficient pollinators as they are apt to visit only flowers which are carrion-scented, and these are likely to be of the same species. (See Fig. 159.)

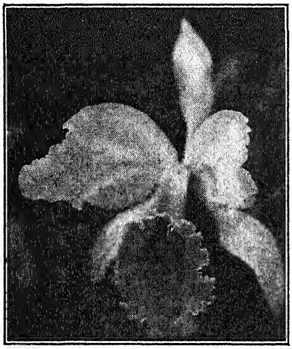

FIG. 160.—Orchid flowers are peculiarly fitted to cross-pollination by insects.

How is cross-pollination brought about? There are two main types of flowers with regard to pollination, **wind-pollinated flowers** and **animal-pollinated flowers.** Wind-pollinated flowers usually have neither showy structures nor marked fragrance. Light, dry pollen is produced in great abundance, and it may be carried many miles by a strong breeze. The receptive structure of the female flower, the stigma, is feathery in form and, when ready for pollination, is covered by a sticky secretion which catches and holds any pollen grains that happen to reach it. In a species having pollen and ovules borne on different plants, as in the cottonwood, only cross-pollination is possible. In other cases the pollen which reaches the stigma may be from a flower on the same plant.

It is significant that the showy and fragrant flowers are animal-pollinated. Differences in flower color and flower structure seem to have a direct relation to the process of pollination, usually to the process of cross-pollination. In some flowers, *Iris*, for example, and the orchid known as lady's slipper, the flower parts are so arranged

that the insect bearing pollen on its body enters the flower in such a manner as to rub against the stigma, and upon leaving, it rubs against the anther. Thus, pollen deposited on the stigma is from another flower.

A very common method of preventing close pollination is by **successive maturing of the stigma and anther** of the same flower; the pollen may be shed before the stigma is mature, or the stigma may mature before the pollen grains. Insects, in going from flower to flower, carry mature pollen from a flower with an immature stigma to another flower having a mature stigma. Here close pollination is impossible and cross-pollination is likely to occur.

FIG. 161.—The moccasin flower, an orchid, a flower peculiarly fitted to cross-pollination by insects.

In some plants, as flax and primrose, there are **different types of flowers.** Some have **long styles and short stamens,** while other plants of the same species have **short styles and long stamens.** An insect visiting the former type of flower receives pollen on the front part of the body and leaves pollen from another flower previously visited on the stigma from the back part of the body. When this insect visits the latter type of flower, the front part of the body, which is covered with pollen, comes in contact with the stigma and the back part of the body receives more pollen from the long stamens.

Sometimes **pollen will not germinate on the stigma of the same flower** or even on the stigma of any other flower on the same plant; or pollen may not germinate as readily on a stigma of the plant which produced it as on the stigma of another plant. In the former case, close pollination is impossible; in the latter, cross-pollination is more likely to occur.

One of the simplest features of flowers which tends to favor cross-pollination and prevent close pollination is the **long style**

of many flowers which brings the stigma out above the stamens. The visiting insect, as it enters the flower, is apt to brush over the stigma, in its exposed position, and leave pollen which it has brought from another flower. Also, pollen from the anther of the same flower can not fall upon the stigma.

Many examples of **highly specialized relationships** between flowers and insects might be given. The pollination of the Smyrna fig is the most remarkable of the known examples of cross-pollination. The details of this process have been noted. (See page 240.)

Fig. 162.—Insect pollination. This butterfly is procuring nectar from the milkweed blossoms, but it is also carrying pollen from flower to flower.

Pollination between anther and stigma on the same plant. Although we have been accustomed to thinking that there must be marked advantages in cross-pollination—and judging from the large number of structural features that fit flowers to this process, and from the results of investigation, we have good grounds for this belief—yet pollination between anther and stigma on the same plant is quite common. Indeed, some flowers possessing features which favor this type of pollination are about as specialized as those which we have noted as favoring cross-pollination. In the **composite family**, each so-called flower is really a head of a large number of flowers, usually of two kinds, ray flowers around the edge and disk flowers in the center of the head. As a rule, in the sunflowers, only the disk flowers produce seeds. Some composites, as the dandelion, mature all the flowers of the head at the same time, but in the greater number, the flowers mature and are ready for pollination from the outer edge of the disk inward, and pollination of all the flowers of a head may require a week or longer. The anthers of a given flower mature before its stigma. As the stigma ma-

tures, it elongates and comes in contact with anthers of other flowers of the head. Thus, pollination between different flowers on the same plant is accomplished, and judging from the vigor of the plants and from the very large number of seeds produced by such composites as wild lettuce, common thistle, dandelion, and sunflower, their method of pollination is very efficient. The pollination of *Yucca* by the *Pronuba* moth furnishes an example of highly specialized close pollination. (See page 240.) Certain flowers (cleistogamous flowers), as some of the flowers of violets, never open. In these flowers seeds are produced regularly in abundance as a result of close pollination. In flowers of this type in which close pollination results from contact of anther with stigma, we have examples of true **self-pollination.** (See Fig 82.)

Exercise 125. What are the essential parts of a flower? Review your study of a flower made in Unit V. Identify in several flowers of different species the anther and filament of the stamen, and the stigma, style, and ovary of the pistil. What is the rôle of each of these parts in pollination and fertilization? Make sketches to show the relative size and arrangement of the pistil and stamen in one flower. Note the position in the flower of the anther in relation to that of the stigma.

Exercise 126. Where in the flower is pollen produced? Study under a microscope (binocular, if available), without water or cover-slip, anthers from different flowers of the same species, one from a flower in the bud, another from a flower just opened, and a third from an older flower. How does pollen get out of the anther? Does the pollen seem sticky and suitable for being carried away by animals, or is it light and dry and suited to wind dispersal? Does there seem to be any certain time when the pollen is ripe and ready for pollination? Can pollen be carried away from a flower before it is ripe? Make careful notes, explaining your answers to the questions of the exercise, and make a sketch to show how pollen is set free from the pollen sacs of the anther.

Exercise 127. How do flowers receive pollen? Study several stigmas under the microscope (binocular preferred) of flowers fully opened. Find pollen which has been transferred to the stigma. What makes it stick to the stigma? How is the stigma different from the style? Find stigmas which seem to be too young to receive pollen. Find others which are too old. What would happen if ripe pollen grains were to touch a stigma either too young or too old. What are two rôles of the sweet, sticky liquid on the surface of a ripe stigma? Explain whether close pollination can occur if the stigma of a flower gets ripe before its pollen, or if the pollen of a flower gets ripe before its stigma. In what way is it possible for close pollination to take place in these two types of flowers?

Exercise 128. Types of flowers with reference to pollination. The flowers of this study will need to be chosen from suitable specimens, representing the different types, which are available at the time the study is made.

Open type flower, as buttercup or nasturtium. Note the relation of anther

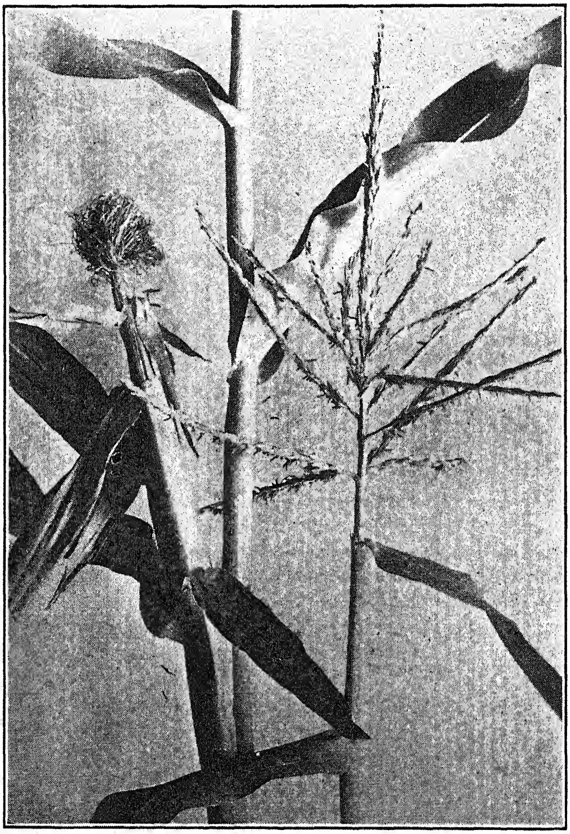

FIG. 163.—Maize, or Indian corn. At left, pistillate inflorescence, or "ear"; at right, staminate inflorescence, or "tassel." (From Robbins, in Botany of Crop Plants.)

and stigma in position. Is the plant **monoclinous** (stamens and pistil in the same flower) or **diclinous** (stamens and pistils in separate flowers)? Describe the flower with reference to odor, color, whether nectar is present, and whether it is **regular** (floral leaves similar) or **irregular** (floral leaves unlike). Describe

the features of the flower which fit it for pollination by wind, insects, contact, gravity, or water. Try to determine whether close pollination or cross-pollination is more likely to occur. Make a drawing of the flower to bring out pollination features.

Specialized flower. Choose for this study a sympetalous (petals united) flower, as butter-and-eggs or snapdragon. Make a drawing of the flower with the floral parts in their natural position. Cut away enough of the flower to show the position of the pollination structures. Is the flower fitted to pollination by wind or by insects? Give reasons for your answer. What structures are present which would attract insects? If insect-pollinated, what insects would be suitable as pollinators? Would cross-pollination or close pollination be more likely to occur? Write a summary of the features of the flower which show specialization, and explain how this specialization is an advantage to the plant.

Composite flowers. Use any available composite, as yarrow, *Coreopsis* or sunflower. Note that the so-called flower is in reality not a single flower, but a head of a large number of flowers set upon a flat receptacle and surrounded by green leaf-like bracts. Separate the head vertically by breaking it open through the middle of the disk. Make a drawing of the exposed flowers to show their relation to each other in natural position. The flowers at the outer margin of the disk mature first, then the other flowers mature gradually from outside to center. The anther matures and sheds its ripe pollen before the stigma of the same flower is mature and ready to receive pollen. The pollen is pulled out of the corolla tube by the hairy style as it pushes out, bearing the immature stigma. The flowers being so near together, mature stigmas of other flowers come in contact with this ripe pollen, bringing about pollination. Insects visiting the head of flowers aid in the transfer of pollen. Pick out suitable flowers of the head, and try to make out the different pollination features outlined above. Sketch under a dissecting lens or binocular microscope disk flowers in different stages of development, one before the stamens appear, another at the time the pollen is ripe, and a third at the time the stigma is mature.

Problem 5. How are fruits and seeds fitted to the process of dispersal of plants?

According to popular usage, the term **fruit** clearly includes such plant structures as peaches, apples, blackberries, and pineapples; tomatoes, peppers, and cantaloupes, on the other hand, are ordinarily classified as "vegetables." To a botanist, the term **fruit** has a much wider meaning. In botany, a **fruit is a ripened ovary, together with any other structures that may have developed with it.** Pollination and fertilization usually result in

the development of the seed, together with the development of the other structures of the fruit. A few fruits, as the banana and certain oranges and grapes, develop without seeds. Fruits may be either fleshy, as grapefruit, or dry, as a grain of corn. In both kinds, however, the principal rôles of the structures which enclose the seed are protection and dispersal.

How are the fleshy fruits fitted to dispersal? The apple, pear, crabapple, and quince belong to the group known as **pome fruits.** The ovary is the core, the ovary walls being the hard plates surrounding the seeds. The fleshy part of the apple is the specialized receptacle which has grown up and around the ovary. During

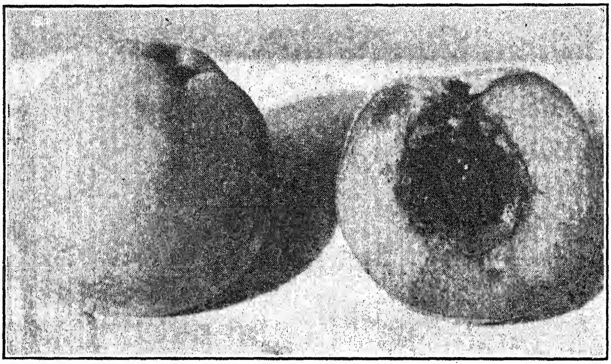

FIG. 164.—The fruit (drupe) of peach with the single seed surrounded by the ovary wall in two layers, the inner one forming the "stone" and the outer layer the pulp.

the time of development, the fleshy part contains starch and is quite sour, because of the presence of malic acid and the absence of sugar at this time. The green fruits are hard, the cells being held together by a substance which is mainly calcium pectate. As the seeds become mature, starch is changed to sugar and the quantity of malic acid may be reduced somewhat. At the same time, the pectic compounds are being broken down into other substances with the result that the cells are separated to some extent and the fruit becomes mealy. The changes in the fruit which make it edible as the seeds develop suggest the rôle of seed dispersal by animals that use the fruit as food. Man has been

especially active in propagation and distribution of these fruits because he has found them desirable as valuable food supplies.

One of the most common of the fleshy fruits is the **drupe**, or **stone fruit**, which includes the peach, plum, cherry, apricot, and olive. The seed is enclosed in a stony layer which we ordinarily consider a part of the seed structure, but which, in reality, is not a part of it. Around this stony layer is a second layer which is fleshy. In all these fruits the stony covering of the seed serves as a protection. The smaller fruits, as cherries, may be swallowed, stone and all, by the larger birds and pass through the alimentary tract without injury to the seed. The chances are favorable that many of the seeds will be dropped in a suitable

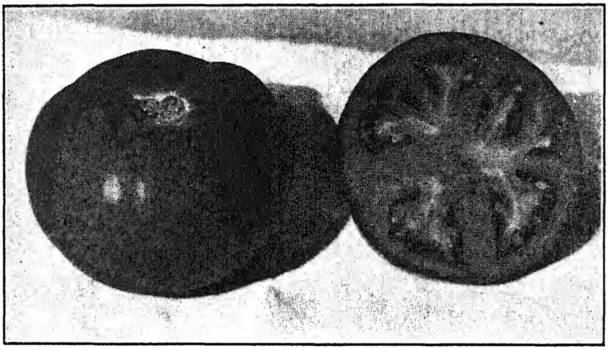

Fig. 165.—The tomato, a berry. The seeds are enclosed in the fleshy ovary wall.

place for germination and growth at some distance from the parent tree.

The **berry** has a fleshy wall enclosing seeds. Berries include the fruits of such common plants as the tomato, currant, grape, blueberry, and cranberry. Seeds of these fruits are small, and many of them are distributed uninjured by the animals that use them as food. The **pepo** is a berry with a hard rind, for example, squash and cucumber. The **hesperidium** is a berry with a leathery rind, as the lemon and orange.

The blackberry is not a real berry in the botanical sense, but is a body formed by a large number of separate ovaries, each a

tiny drupe, attached to a single receptacle. The raspberry is similar to the blackberry, but the mass of fruits becomes detached from the receptacle when ripe. The strawberry is really not a fruit at all, but a fleshy receptacle bearing numerous tiny **achenes,** containing the seeds, on its surface. Each of these achenes is, in reality, a tiny fruit. Fruits of this type are known as **aggregate fruits.**

The mulberry and pineapple are formed from many individual flowers all fastened tightly together, and for this reason are called **multiple fruits.** The Smyrna fig is a **syconium,** consisting of a fleshy, hollow receptacle, the one-celled ovaries developing into nutlets which are embedded in the inside wall.

Fig. 166.—The aggregate fruit of the raspberry, made up of many separate fruits massed on a single receptacle and developed from a single flower.

The fruits mentioned in the foregoing discussion either have fleshy ovary walls or are developed in connection with other fleshy flower parts which are edible. Most of them are characterized, in addition, by being attractively colored, shades of blue, red, and yellow being especially prominent. Practically all of them are green in color and inconspicuous before maturity, becoming edible and showy as the seeds ripen. Because of the possession of these features, animals have a prominent rôle in the dispersal of many of the plants which produce these attractive, fleshy fruits.

How are dry fruits fitted to dispersal? The dry fruits are of two types, **dehiscent** (splitting open when ripe) and **indehiscent** (not splitting open).

Dehiscent fruits. Among the dry, dehiscent fruits, the **legume** is a common example. The pod of the garden pea or bean shows

the characteristics of this type of fruit. You can not help noting, in shelling peas, the resemblance of the opened pod to a leaf, the outcurved edge of the pod being the midrib. You have probably noted that the seeds are fastened to the pod at the incurved suture. The opened pod shows that the legume is, in reality, a modified leaf, in this case a single carpel bearing seeds at the edges. When the legume dries, it usually splits open at the two sutures, the two halves of the carpel curling in such a way as to expel the seeds.

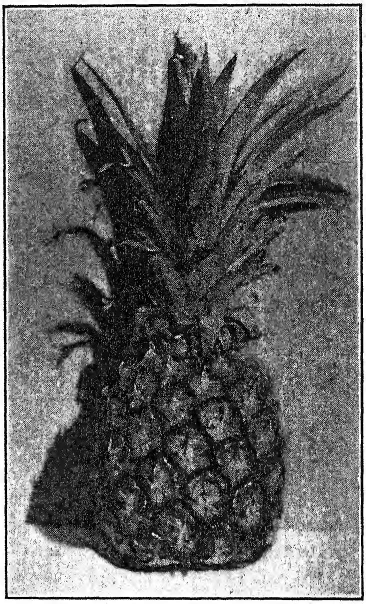

Fig. 167.—Multiple fruit of the pineapple. The fruit is developed from the ovaries of many separate flowers.

The **follicle** is a dry fruit developed from a single carpel which opens along one suture. You may have noted in your garden the opening of the follicles of larkspur, or those of columbine, at the top and along the inner edge in such a manner that the dry seeds are thrown some distance as the tall stem is swayed about by the wind. The fruit of the poppy or that of the violet is an example of a **capsule**. Capsules open in different ways, allowing the seeds to drop or be thrown out by movements caused by the wind. The **silique** is made up of two carpels which open at maturity, the two valves curling upward leaving a partition from which the dry seeds become detached. Most of the members of the mustard family have this type of fruit.

Dry indehiscent fruits. A very common example of a dry indehiscent fruit is the **achene**, represented by the fruit of the sunflower and by that of the buttercup. The single seed is attached to the ovary at one point only. A grain of corn, typical of the fruit of the grasses, is a **caryopsis**. Corn meal, as you buy it,

consists of granular bits of the endosperm and embryo of the seed, the tough fragments of ovary wall and the testa having been sifted out in the process of milling. The **samara** or key fruit has the ovary expanded in such a way as to form wings. Examples of plants producing this type of fruit are ash, maple, elm, and hop tree. What is the significance of the fact that winged fruits are common among trees? The **nut,** as the acorn, chestnut and hazelnut, is similar to an achene, but has a hard outer wall. Though nuts are eaten in large numbers by animals, many that are buried by squirrels are never found, and so are in a suitable place for germination.

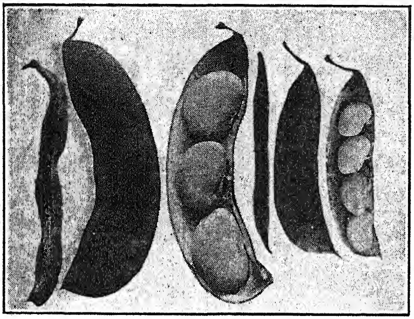

FIG. 168.—The fruits (pods) of Lima beans.

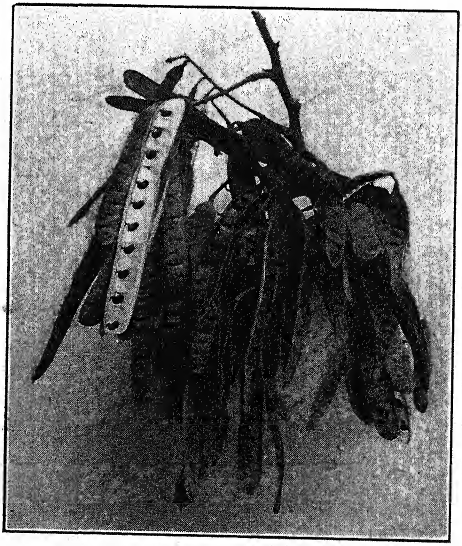

FIG. 169.—Fruits (pods) of the black locust.

It is possible, also, that many fruits of oak, hickory, and walnut are carried away in time of flood and deposited by water on a bank where germination and growth of the seeds may take place.

By what means are fruits and seeds dispersed? Dispersal by propulsion. It has been noted in a previous section that legumes disperse their seeds by a curling of the two halves of the dried pod in such a way as to throw the seeds some distance. The well-known garden balsam or touch-me-not has a pod which suddenly explodes upon being touched and a violent curling of the carpels throws the seeds out with considerable force. When one walks among jewel weeds (*Impatiens*) in the woods in late summer, one can hear seeds falling all about as a result of the bursting of the fruits.

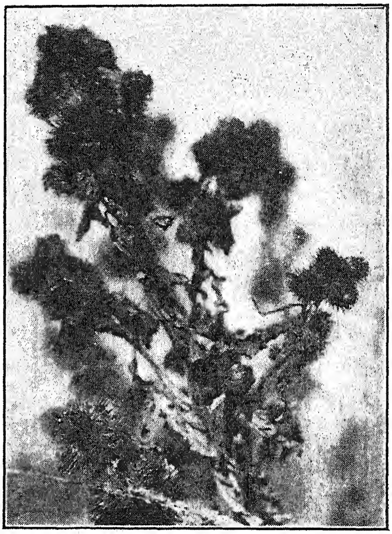

FIG. 170.—The fruits of burdock are provided with hooks which fasten the fruits to passing animals.

Dispersal by water. Many seeds have walls that are not readily penetrated by water. These may retain viability for a long period while being carried great distances by water. As the water recedes, many seeds are left in the silt of flood-plains and on banks where they have suitable conditions for germination.

Dispersal by animals. The farmers of the country suffer huge losses every year on account of burs which get into the wool of sheep and reduce its value. Fruits with reflexed spines and barbs, as burs of cocklebur and burdock, beggar ticks, and Spanish needles, cling to the furry or woolly coats of animals and to the clothing of man and may be carried miles from the plant which produced them. Our worst weeds have been brought into the United States from abroad by man on his clothing, in his luggage, and in farm and garden seeds that he has imported, and they have

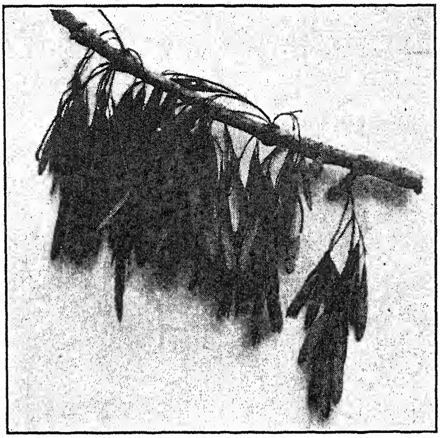

FIG. 171.—Dispersal by the wind. Fruit (samara) of white ash.

been scattered throughout the country over man's highways and his railroads. We have already noted the dispersal of seeds by birds that eat fleshy fruits and drop the seeds in places suitable for growth.

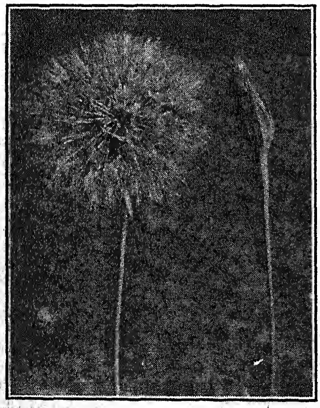

FIG. 172.—Fruit dispersal. Fruit heads of the composite, goat's beard. The opened head at the left shows the fruits, each with its parachute, ready to be lifted and carried away by the wind.

Dispersal by wind. If you live near cottonwood trees, you have noticed, in late spring, "cotton" flying about. If you have examined some of the cotton, you have noticed that tiny seeds are attached to the small tufts. In this way seeds are carried by the wind. Dispersal by the wind is wasteful, but it is effective. Seeds of some of our most troublesome weeds, as wild lettuce and Canada thistle, are scattered far and wide by means of wind which lifts the parachute attached to the seed and carries parachute and seed high into the air and possibly for miles before they are dropped. Various states have at-

tempted to cope with the Canada thistle menace by enacting laws requiring owners of land to keep all thistles mowed before they blossom in order to prevent any production of seeds. The tumbleweeds, as tumble mustard, winged pigweed, and Russian thistle, branch in such a way as to form a large spherical mass which, when mature, breaks off near the ground and goes tumbling before the wind, scattering ripe seeds as it goes. When we realize the possibilities of wind dispersal of plants, we are reminded that weed prevention on our premises is not only profitable for ourselves, but is also a *civic duty*, since weeds are no respecters of fences and, if allowed to grow in our own fields and gardens, are sure to spread to those of our neighbors.

Exercise 129. What is a fruit? Examine fruits of the following list and make sketches, labeling the parts of the flower, as ovary, style, receptacle, stigma, represented in the developed fruit: bean, grain of corn, sunflower, prune (soaked for study), maple.

Explain whether the definition of a fruit as " a ripened ovary " holds for the fruits mentioned above.

Examine and sketch in the same way the following fruits: apple, pineapple, strawberry.

Explain whether the definition of a fruit suggested above holds for these fruits. If it does not, use your labeled sketches in revising the definition to include all fruits.

Exercise 130. What are the different types of fruits? Using your sketches made in the previous exercise, together with your text, classify the fruits in the lists of Exercise 129 and others, and give the characteristics of each type of fruit, as: Bean, **legume or true pod**—dry, dehiscent; one carpel, splitting along two sutures.

Exercise 131. How are fruits and seeds dispersed? Study available fruits to determine probable means of dispersal and describe structural features which aid, using sketches where desirable. Make lists under the headings as follows:

1. Dispersal by propulsion, as sweet pea, witch hazel.
2. Dispersal by attachment to animals, as cocklebur, burdock.
3. Dispersal by means of indigestible seeds of fleshy fruits that are eaten by animals, as raspberry, black haw.
4. Dispersal by wind, as dandelion, ash, tumbleweed.
5. Fruits and seeds without obvious means of dispersal, as acorns.

Suggested activities. (*a*) Make a collection of fruits found in the market and classify on basis of type; as apple—a pome fruit.

(*b*) Make collections of dry fruits and classify on basis of means of dispersal.

ADDITIONAL QUESTIONS AND EXERCISES

1. Explain why the stem of a plant placed in a horizontal position in darkness will grow upward at the tip.

2. What will happen if onion sets are planted upside down in the soil?

3. Explain why gladiolus corms will send out roots and shoots more quickly if the dry scales and other dead parts are removed from the corms before planting.

4. Why do celery stalks (leaf petioles) grow taller if the soil is banked up around the plants?

5. Why is celery more crisp and tender when banked with earth than when allowed to grow without banking?

6. In selecting strawberry plants, why is it safer to get plants from a neighbor who has a successful strawberry patch than to send away to another part of the country for plants of an advertised, fancy variety?

7. If a farmer is moving to a distant part of the country in about the same latitude, he might take farm seeds along with him, or he might wait and get seeds from farmers in the new location. What would be your advice? Explain.

8. What is the advantage of the deciduous habit?

9. Why is it necessary for the leaves of the evergreens of our colder regions to have xerophytic structures?

10. Why is it a good plan to give the soil about the roots of ornamental evergreens a good soaking with water on the approach of cold weather?

11. In growing plants in a region new to you, what use could you make of information concerning the native wild plants growing in the vicinity?

12. Should a farmer who raises red clover permit the boys to destroy bumblebees' nests? Explain.

13. Why do gardeners have a hive of bees in a greenhouse where cucumbers are grown?

14. Explain reasons for the practice of spraying fruit trees with poison, for destroying codling moth, once just before the blossoms open, and a second time just after the petals have fallen, but avoiding spraying while the trees are in full bloom.

15. What do honeybees gain from buckwheat blossoms, and what does buckwheat gain from visits of honeybees?

16. Of what advantage is it to the carrion flower to possess an odor similar to that of decaying flesh?

17. What kinds of flowers cannot be close pollinated?

18. What kinds of plants cannot be cross-pollinated under natural conditions?

19. What advantage is it to the species to possess flowers in which both cross- and close pollination are possible?

20. In what way might wading-birds carry seeds and place them in a location suitable for germination?

21. Why are some of our most persistent weed pests found among the composites?

22. Explain why saturating the soil about the roots of Canada thistle with strong salt solution will kill the plants.

23. Explain why ragweeds appear in the stubble of grain fields, although few weeds were noticed while the grain was standing.

24. Why is it necessary to dig weeds from a newly seeded lawn although little weeding is needed in an established lawn?

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UNIT VIII

THE DEVELOPMENT AND IMPROVEMENT OF PLANTS

One of the fundamental laws of nature is that **life comes from life.** Man has been able to do wonderful things in the chemical laboratory, but he has not been able to produce any substance with the properties of living material. Geology teaches that the earth has gone through a series of changes in its development, and that life has existed on the earth during at least half of its geologic history.

Much is known of the early plant forms from studies of their fossils. These records also reveal something of the story of the development and disappearance from the earth of great plant groups as well as the rise and development of those which have become the dominant plant groups of today.

Primitive man was able to use plants in many different ways in his daily life. They were food, shelter, medicine to him, and they beautified his landscapes. The same laws which were in operation in nature changing plants in the wild were also changing the plants which man had brought under some degree of cultivation and control. Man early learned to take advantage of the changes in plants which made them more suitable for his uses, and he became a plant breeder. It is true the methods he used were haphazard at first, but in the end they were effective in securing better plants to meet his needs.

It had long been known that **plants tend to be similar to their parents,** that is, that certain characteristics are inherited by offspring. It is also known that **no two plants are exactly alike,** that **offspring tend to be different in certain respects from their parents.** In other words, **plants show variation.** It was not until the middle of the nineteenth century that it was shown that living things inherit characters from their parents in a certain way and that inheritance in nature obeys fixed laws. Discovery

of the laws of heredity by Gregor Mendel opened the way to the explanation of what man had been able to accomplish in the development of improved strains of plants. It has also simplified the processes of plant breeding and introduced the new science of genetics.

The economic importance of plant improvement to the people of the world may be illustrated by improvement in wheat. As an example, Roberts of the Kansas State Agricultural College made collections of wheat from all parts of the world and especially from the wheat-growing regions where conditions are similar to those of Kansas. An early winter with little snow killed most of the wheat in Kansas. There was one exception. A plot which Roberts had planted with seed imported from southern Russia passed through the winter without serious harm. The seeds were carefully saved and planted, and from this beginning was developed the Kanred variety which not only was frost resistant, but also ripened earlier than other Kansas wheats, was more resistant to stem rust, and the flour of which proved excellent for bread-making.

Plant improvement has been of untold benefit to the plant grower, who has been able to produce larger and better crops, but it has been of even greater benefit to the consumer, who can get cereals, fruits, and vegetables of higher quality and at less cost than would be possible with unimproved varieties of plants.

Problem 1. In what ways have plants changed?

At least 250,000 different species of plants are living on the earth at the present time. Rocks are found which contain fossil remains of simple plants which lived in the remote past—it is judged around one thousand million years ago. It is impossible to conceive of the time expressed in that figure. The time covered by the average life span of a human being is only a fraction over a second as compared with the time covered by the history of plants as found in the rocks.

Botanists believe that simple plant life came into existence at a much earlier period than that represented by the record of the rocks, and that from the beginning many plant forms have come

and gone, others have remained and become the ancestors of the plant life that we see on the earth today. We can ask many questions concerning the nature of the first forms of life on the earth, but no one has been able to answer definitely any of them. They were certainly very simple, probably small bits of jelly-like protoplasm possessing the powers of assimilating food, respiring, growing, excreting wastes, responding to stimuli, and reproducing. These are the outstanding properties of living matter, protoplasm, the most wonderful of the different forms of matter of which man has any knowledge. From the very beginning of life, there has extended a line or lines without a break—living material giving rise to more living material. We can trace back in our imagination this line from every living thing now on the earth through all the countless years to these simple sources.

The simplest forms of plant life must have lived in the presence of water, probably in the sea. They must have been so delicate that even the slightest amount of drying would have destroyed them. Among the simplest forms of plant life which we know at present are the bacteria. It is thought that bacteria in the past had an important part in the separation of calcium carbonate from the sea-water and in the resultant formation of the great deposits of limestone which we find in various parts of the earth. It is believed, also, that bacteria have been responsible for the laying down of certain deposits of iron ore and of the graphite from which the lead in pencils is made. Scientists have estimated the time which must have elapsed during the formation of these deposits, and from the estimates have been able to guess concerning the antiquity of such simple plants as bacteria. Whatever the forms of early life were, there must have been changes which tended to fit these forms to the changing habitats in which they lived. As time went on, some appeared which could live on land in the moist air of those early periods. From these early land plants have developed our mosses and ferns and finally the seed plants. As plants progressed, those changes which were advantageous tended to add to the chances of survival. Changes were not all in a direction which proved an advantage. On this account great numbers of plants which once lived on the earth have gone out of existence. We have abundant evidence of this

fact in the fossil remains of plants which are found in the sedimentary rocks such as limestone, sandstone, and shale.

We are led, in our discussion of the changes in plants, to the two statements: first, that **plants of today are descendants of plants that preceded them, and these in turn came from other plants**; second, **in time certain forms came to be different from their ancestors.** We are led to believe that new plants will appear on the earth in the future in the form of modifications of plants that are now living.

Problem 2. How do we know that plants have changed?

Botanists who have made a study of the evidences of change in plants in the progress of their development on the earth have offered facts to prove to their own satisfaction that the plants of the present are modified descendants of the plants which preceded them. First, a great variety of plant forms are found as fossils in the rocks and coal deposits. Second, the geographical distribution of plants as they are found today indicates that many families had their origin in early forms in some particular part of the earth's surface from which their descendants gradually spread to other regions. Third, plant forms of today have a remarkable similarity to each other in structure and function of parts. Fourth, the plants of today are remarkably similar in their cycle of life. Fifth, plant breeders have developed new forms which could easily be mistaken for distinct species. Sixth, man has found forms in nature (mutants) which are distinctly different from their parents.

What are fossils? Have you ever gone fossil hunting? If you have, you know the thrill one gets upon releasing, from its rock prison, a record made millions of years ago when your plant was shut off from the light of day by a deposit of clay or sand which subsequently turned to stone deep down in the earth. A blow of your hammer brings to light again after all these years what is left to show of the plant life which existed in times which are now remote geologic history.

Ancient plants have been preserved as impressions. Some part of the plant was covered by clay, sand, or mud, and this

left a permanent impression in the material which, subjected to great pressure and age, turned to stone.

Much of our knowledge of plants of the past has been gained from a study of impressions found in the layers of rock just above beds of coal. Fig. 173 shows such an impression of a fern leaf in a piece of shale taken from a coal mine in Illinois. It was removed from a position in the earth 60 feet below the present surface.

FIG. 173.—Fossil of a part of a frond of a seed-fern. These ferns formed a part of the plant life of the Coal Age forests.

What we know as **petrified wood** is not in reality wood at all. Fig. 174 shows a piece of so-called petrified wood. It has the grain and even the cell structure of wood. The original wood or plant part was covered with water which contained in solution a large amount of mineral matter. This material penetrated the wood, and as the wood decayed the mineral matter took its place; when the process was complete the rock material had taken the form of the original plant material.

In the earliest rocks few fossils of plants are found. There may have been many more plants than the fossil remains indicate, but during the millions of years which followed, the rocks were subjected to the effects of running water, high temperatures, and enormous pressures, any one of which conditions could have destroyed the record.

FIG. 174.—Note the resemblance of this "petrified wood" to real wood.

Fossils of the different geologic periods show that simple plant structures were succeeded by structures more complex as plant groups succeeded one another in the long period of their development. The records show that great groups of plants declined and entirely faded from the picture. The first seed-bearing plants were fern-like. The flowering plants as we know them today are a comparatively recent development. In general, the simplest plants are found in the oldest fossil-bearing rocks. The

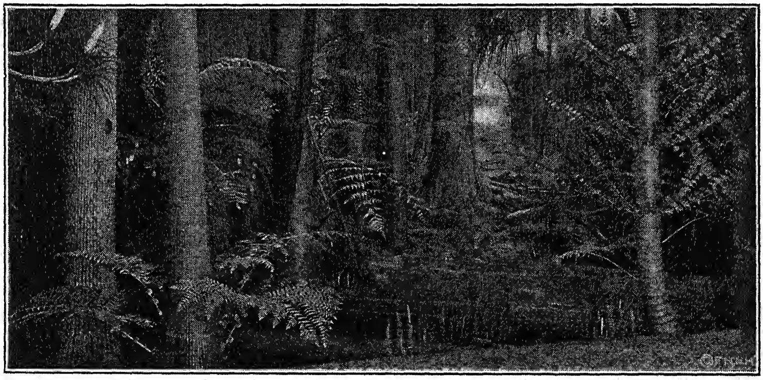

FIG. 175.—Ferns and cycads. It is thought that the vegetation in many parts of what is now temperate America was something similar to this a hundred million years ago. (Photograph furnished by the Field Museum of Natural History, Chicago.)

fossils of more complex plants are found in the rocks of later times.

The first seed plants to attain prominence in the earth's flora were all gymnosperms, that is, forms with seeds not enclosed in an ovary such as our own living cone-bearing trees, like pine and spruce. Many of these plants became extinct at about the time the angiosperms (flowering plants with enclosed seeds) were becoming established. The few forms of these early plants which remain are the fern-like cycads of the tropical regions of both the eastern and western hemispheres, and the maiden-hair tree (*Ginkgo biloba* of China) which is the lone survivor of what was a large order of trees at about the time the flowering plants were becoming numerous.

FIG. 176.—*Cycas revoluta*, the "sago palm" of our conservatories.

Evidences from geographic distribution. Geologists tell us that in the course of geologic time the earth has undergone many changes which affected plant life. During the millions of years in which the plant material that later became coal was being laid down, the nature of the plant life over the earth was extremely uniform. During this time and, indeed, over much of geologic time, the climate must have been uniformly warm and moist over most of the earth's surface. Under these conditions plants of the same group could have almost world-wide distribution. Because of the more uniform conditions in water than on land, algae and other water plants of today are more widely distributed than species of land plants. It has been noted in a previous unit

FIG. 177.—Dioon, a cycad. Note the resemblance to the ferns from which the cycads came.

that, through changes in such plant structures as leaves or flowers, plants are able to meet the conditions of a changed environment. Plant groups that cannot change are eventually crowded out by others more suited to the changed conditions. We probably have the explanation in these facts for the entire destruction or reduction to a mere vestige of great groups of plants in different periods of geologic time.

Barriers, as oceans, mountain chains, or deserts, have the effect of isolating plant groups. It is believed that at different times in the history of the earth the land masses were very different

FIG. 178.—Zamia, showing carpellate cones. The cycads, to which this plant belongs, are the most primitive of the living gymnosperms.

in form and extent from the continents as they are at present. North America and Asia were once connected by a land bridge. There is also evidence that Europe and America were connected by land in the north Atlantic, and that, in the south Pacific, South America and Australia were more or less connected at a very early period.

At about the time the flowering plants were becoming established as a future dominant group, the Gulf of Mexico extended to the Arctic Ocean, forming a barrier between the eastern and west-

ern parts of the United States. With this invasion by the sea here and in other parts of the earth, climatic conditions being mild and moist, there was rapid development in plant life. In the rocks of this period are found such modern trees as oaks and willows, along with many other genera of plants now living.

Following this era there was a period of mountain building, especially in the western part of the United States, and of land elevation, and North America came to have about its present form and elevation. With these changes in land contour came changes in climate until it was probably about as it is at present. The Pacific slope was a region of dry summers and mild wet winters, and the eastern part of the United States had moist summers and severe winters. These regions were separated by two great barriers, the mountains of the west and the dry plains to the east of the mountains.

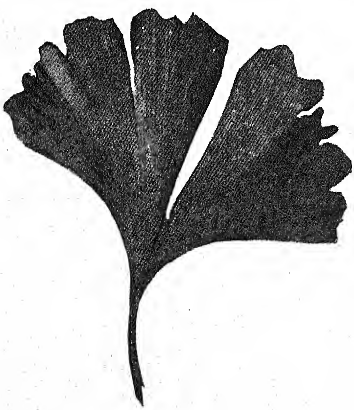

FIG. 179.—Leaf of the maiden-hair tree, or ginkgo, which is one of the most ancient of living trees.

With these changes of conditions came a sorting out of the plants. It is fair to assume that the trees of the west slope and those of the east slope had the same or similar ancestors. But because of the differences in climate, the vegetation developed in different ways. On the west slope the trees are mainly conebearing; on the east they are mainly deciduous. It is stated that of the nearly one hundred trees native to California only two kinds are found east of the Sierra Nevadas.

In general, closely related species of plants are found living in the same geographic region, as if the family had its origin in some particular center and gradually moved out from that center. The cactus family seems to have had its origin in the Mexican plateau, whence it spread widely into regions to which it was

suited. It has been diversified until there are now about 1500 separate species. No other continent has native cacti.

Evidence of change from similarity of structures and rôles. In studying plant cells, it makes little difference what cells we study inasmuch as the structure is in general the same. We recognize in each a nucleus, cytoplasm, and a wall of cellulose. Some cells are more easily studied in the living state than others, so we select our living cell from the tissues that are not too complex, or we select a single-celled plant. True, some cells are simpler than others. A bacterium does not have a clearly defined nucleus. The nuclear granules are diffused throughout the cytoplasm. The bacterium is considered a primitive type of cell. Another primitive cell is that of the blue-green algae.

Any organ or system in the more complex plants might be chosen for comparison, and we would find a remarkably similarity in structure. Leaves of plants under similar conditions of light, temperature, and moisture are remarkably similar. Likewise, all plants which make food make use of sunlight and raw materials similarly. Absorption and digestion are accomplished in the same general way. Thus comparative anatomy and physiology offer many facts which give us reasons for believing that plants of the present came from pre-existing forms.

Evidence from the results of experiments. If we could carry on a series of experiments and actually see a new species of plants come into existence, the riddle of life would be very much simplified. In one way or another, forms of plants in the wild have been improved by man for his own use. Some plants, such as wheat and apple, have been under cultivation for so long a time that we do not know for certain what their wild ancestors were or just where the improved forms were developed. The Indians were growing maize long before the white man landed in America. The potato is also a product of our country, but the form we grow is quite different from any other member of its group, the nightshade family, which is found growing wild today.

Numerous varieties of plants have been developed as a result of the cultural practices of the practical farmer, gardener, and fruit-grower, but not a single entirely new species. Many other varieties have been developed through experiments by trained

biologists, but even trained biologists have not been able to produce a new species.

When we examine the parents of the hundreds of different varieties of the cultivated *Chrysanthemum* and compare the parents with their descendants we are struck by the wonderful changes that have been brought about in developing, from a plant with yellow flowers less than an inch across, to plants more than six feet tall and with flowers of many colors and shades eight or even ten inches in diameter. Numerous other examples could be cited from the abundance of evidence of changes in plants

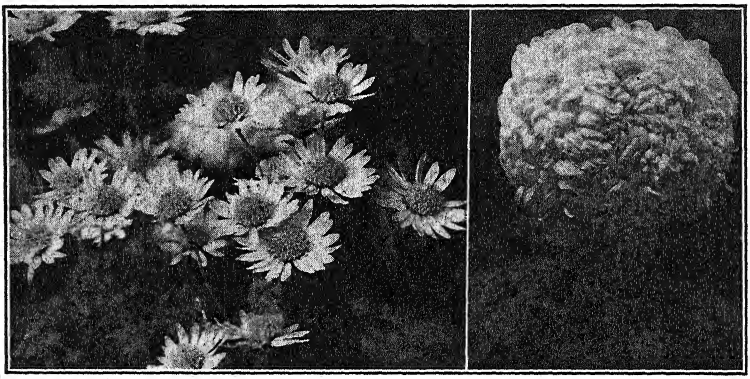

FIG. 180.—At left, *Chrysanthemum indicum,* with flowers an inch in diameter, one of the ancestors of our showy cultivated chrysanthemum; right, an improved variety, a descendant of *Chrysanthemum indicum.*

brought about in connection with plant propagation and improvement.

Exercise 132. Study any available rocks showing animal or plant remains. Find out from your instructor the kind of rock in which your specimen is embedded. Is your fossil an impression, plant or animal remains, or an infiltration of mineral matter taking the place of the specimen? How do geologists tell the probable age of fossils? Under what conditions was your fossil formed? Try to determine its probable age. Make a drawing of the specimen in your notebook.

Exercise 133. Copy a map in your notebook showing the condition of the continent of North America at the time of the ice age. What changes in climate brought about the ice age? What changes caused the ice to disappear?

What changes in the plant life of the continent were brought about by the ice age?

Exercise 134. Using tree books, make a list of trees which are found only west of the Cascade Mountains and another list of trees found in the eastern part of the United States. Are the same species of trees found in both regions? Account for the likenesses or differences in the character of the vegetation in the two regions.

Problem 3. What are the method and cause of change in plants?

The young or progeny of plants tend to resemble their parents. We have reason to expect nasturtiums to grow from nasturtium seeds and sweet peas from the seeds of sweet peas. Besides, if we desire dwarf nasturtiums, we plant seeds from plant parents which are dwarf in habit, and if we want pink sweet peas, we select the seed from plants which bear pink flowers. **The tendency of offspring to resemble their parents is known as heredity.**

A plant which results from vegetative reproduction shows a remarkable similarity to the plant from which it came. A strawberry sends out runners upon which appear buds, and from these buds grow adventitious roots which fasten them to the soil. After awhile the bud with roots is able to lead an independent life, and the connecting runner from the parent plant withers and dies. The young plant, under suitable conditions, will grow into a plant similar to its parent in character of leaves, size and flavor of fruit, and in fact, similar in every other respect. This is an example of vegetative reproduction. In general, the results in every other example of vegetative reproduction are similar to those related for the strawberry.

Why are plants which are produced by vegetative means similar to the plant which produces them? Every plant starts as a single cell. This cell divides and forms two similar cells by the process known as simple cell division. In this process there is a division of the cytoplasm, and across the dividing cell is formed a partition consisting of two walls so that after division each of the daughter cells is completely surrounded by a cell wall. But most important of all, in cell division there is a division of the nucleus of the cell into two exactly similar parts. This division of the

nucleus has been carefully studied under the high power of the microscope. The details of nuclear division can not be studied in living cells. Growing structures, as the tip of a young onion root, are killed so that the processes of cell division stop immediately. Then they are prepared for examination under the microscope. Careful staining brings out the structures so that they can be studied.

Cell division. Scattered through the nuclear protoplasm and arranged in a sort of net are granules of material which stain more deeply than any other parts of the nucleus. The material which makes up these granules is known as **chromatin.** When a stained lengthwise section of a young root tip is examined, most of the cells are seen to be in the **resting condition** with cell wall, cytoplasm, and the nucleus in which are the chromatin granules plainly showing. A careful study of the section reveals some cells in which the chromatin granules are no longer in the net arrangement, but have taken the form of a dense coiled ribbon in the nucleus. It has been found that this is not a single ribbon but rather one with a division along the middle throughout its length. This double ribbon is recognized as a beginning stage in simple cell division and is known as the **spireme.**

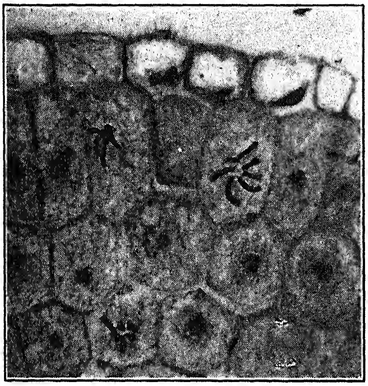

FIG. 181.—Cells near the tip of an onion root, showing in three cells the darkly stained chromosomes. These three cells are in a state of division, whereas the remainder of the cells are resting.

Looking further among the cells of our preparation we see that in certain cells the spireme has broken up into a number of sections and that each section has divided into two exactly similar parts. The sections are of various shapes and are arranged in a plane across the cell midway between two sides.

Examining still other cells, we find a peculiar behavior. It is just as if an elastic thread were attached to each section and with

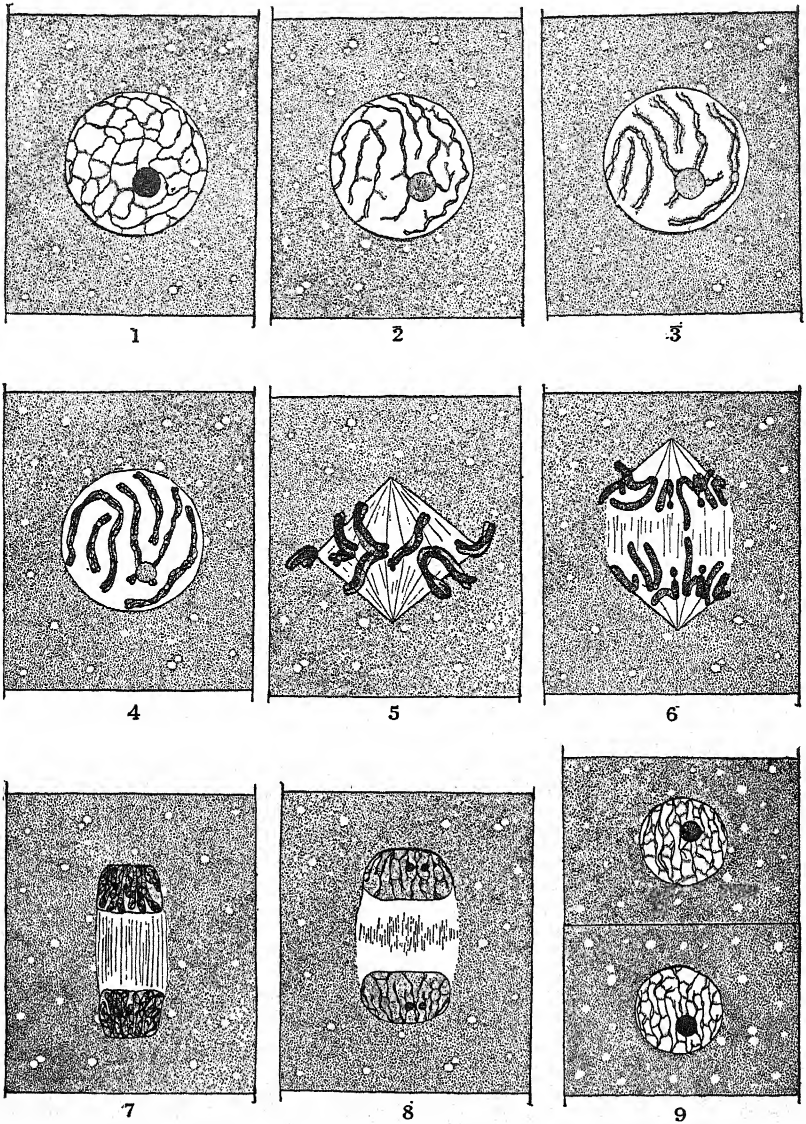

FIG. 182.—Stages in cell division. (The nuclei redrawn from a figure in Sharp's Introduction to Cytology, 3rd Edition. McGraw-Hill Book Co.)

the other end of the thread attached near the ends of the cell (the poles of the cell), half of the threads attached to one pole and half to the other. Cytologists (persons who study cells) have found that one section of a pair seems to be attracted or drawn to one pole and the other section of the pair to the other pole. Some force causes the two members of each pair of sections to separate and move towards the opposite ends of the cell. Some cells of the preparation will show the sections in an aggregation at the two poles of the cell, and since each group contains a section from each pair the two groups will be exactly similar in number and kinds of sections. These take a deep stain and for this reason have been named **chromosomes.**

Other cells of our preparation will show cell walls forming across the equator of the mother cell, the chromosomes breaking up into chromatin granules and the cell division nearing completion, after which the two daughter cells may be called resting cells. We now have two similar cells which have resulted from a division of material contained in the mother cell.

What are chromosomes? Biologists who have made a study of heredity are of the opinion that characters are handed down from parent to offspring by means of the chromosomes of cells. Small bodies of material are contained within the chromosomes, and these carry something which determines the characters of the new individual. These bodies are known as **genes** or **determiners.** Each chromosome seems to be made up of a large number of genes or determiners, and when a chromosome divides in cell division the process includes a division of the determiners so that the two daughter cells will have exactly similar determiners. That is why the daughter cells are similar to each other and also similar to the mother cell from which they came.

When a new plant develops from a portion of stem, leaf, or root of another plant by vegetative reproduction, the determiners in the cells of the new plant are exactly similar to those of the parent plant. Though the surroundings may have the effect of modifying the form and size of the offspring, in general the young plants tend to be similar to the plant from which they came. They are really a part of that plant set over into a new environment.

Exercise 135. Why do the two daughter cells resulting from simple cell division have similar characteristics? In this exercise you will see cells in the resting condition and different cells showing various stages in simple cell division (mitosis). It is not easy to find and study the progress of cell division under the high power of the microscope, but it is necessary to know what takes place in a dividing cell in order to understand inheritance. So, with the help of your teacher and by referring to models of dividing cells or to the drawings in your book, you will be able to identify dividing cells in the prepared slides.

Examine, under the low power of the microscope and then under the high power, a lengthwise section of an onion root tip stained to show cell structure. Look for resting cells and cells in the process of division. In general, how are the dividing cells different from the resting cells? Why is the root tip a good place to find dividing cells? What is the result of cell division in the root tip?

Read the description of cell division given in the preceding pages, and compare the description with what you see under the microscope.

Make a series of six enlarged drawings or diagrams of cells as follows:

1. Resting cell, showing:
   a. Cell wall.
   b. Nucleus.
   c. Chromatin network.

2. A cell showing a nucleus in which the chromatin network has become arranged in a continuous looped band or spireme.

3. A cell showing separation of the spireme into definite pieces or chromosomes.

4. A cell showing the chromosomes arranged in a plate across the middle.

5. A cell showing the half-chromosomes moving to opposite poles of the cell.

6. Formation of cell wall between two daughter nuclei resulting in two new cells.

The cell of the onion root tip has been found to have sixteen chromosomes. How many chromosomes has each of the daughter cells? What is the source of the chromatin material in the daughter cells? Remembering that chromosomes are thought to be bearers of determiners of characters, explain:

1. Why the daughter cells are similar to the cell from which they came.

2. Why the daughter cells are similar to each other.

3. Why the vegetative cells of a plant that started from a single cell (the fertilized egg) bear the same hereditary characters.

4. Why the vegetative cells of plants which are started from cuttings bear the same hereditary characters.

What is the inheritance of plants that have two parents? In a plant that is the product of sexual or gametic reproduction two lines of heredity are represented. You will remember that in gametic reproduction of flowering plants the sperm or male gamete, produced in the germinating pollen, unites with the egg

or female gamete, which develops within the ovule, to form the **zygote.** Thus the chromosomes from the sperm cell together with the chromosomes from the egg cell are the chromosomes of the zygote. You can see that the zygote, then, carries chromosomes with their genes which came from the plant which produced the sperm and also chromosomes with their genes which came from the plant which produced the egg. The young plant which develops from the zygote will be made up of cells each of which has chromosomes with their genes which came from both of the parents.

The vegetative cells of plants of any species all contain the same number of chromosomes. Each sex cell or gamete contains half as many chromosomes as are found in a vegetative cell or zygote. The chromosome number is halved in a peculiar kind of division in the process of formation of the gametes, and moreover, there is an assortment of the hereditary determiners.

When a zygote is formed from fertilization of an egg of one plant by a sperm of a plant of another strain or species, the plant which results is called a **hybrid.** In cross-fertilization there is a combination of determiners. As a result many different kinds of hybrid plants may come from the same parents. Thus another way in which plants change results from cross-fertilization. This is known as **hybridization.**

The combination of characters which a plant inherits from its parents may be such as will make the plant less fit to meet the conditions of the surroundings than either of the parents. In this case the plant will not survive in competition with other plants. On the other hand, if a plant inherits the strong characters instead of weak characters from both parents, then the plant will succeed and leave offspring which may crowd out plants of other strains which are not so well fitted to the environment. In this way new strains of plants are coming into existence and old strains are disappearing.

Why do offspring from hybrid parent plants differ? About the middle of the last century, Gregor Mendel, an Austrian monk, learned much about heredity by experimenting with common plants in his garden. In one experiment he planted wrinkled peas and smooth peas and was careful to give both the same kind

of growing conditions. When they were in bloom he removed the anthers from the flowers of the one set of plants, say the ones from round seeds, before any pollen was ripe. At the proper time he transferred pollen from the plants from wrinkled seeds to the stigma of the flowers without anthers. This was **artificial cross-pollination.** The result was **cross-fertilization.** The sperm

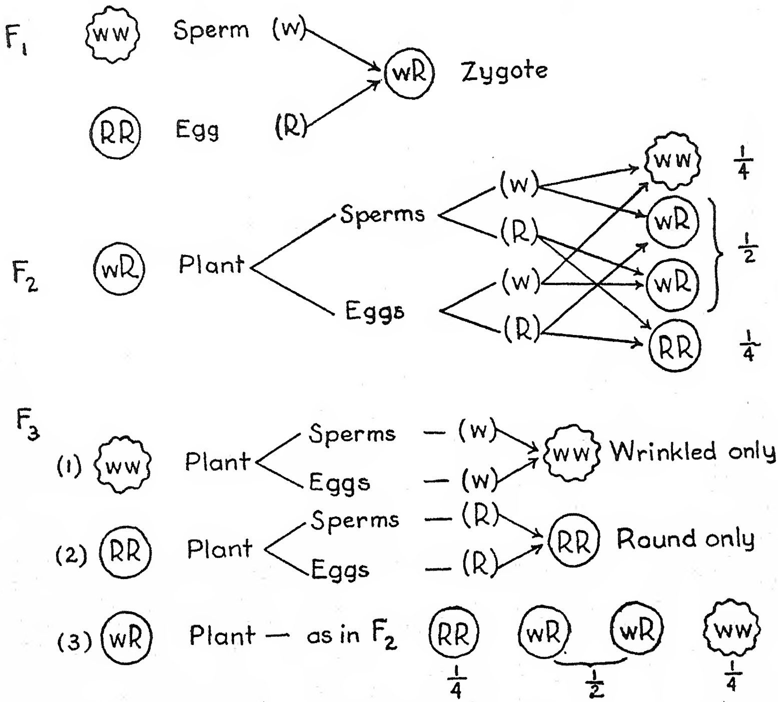

FIG. 183.—Diagrams illustrating Mendel's laws of heredity. (*w*) indicates presence of the determiner for the recessive character, wrinkled; and (*R*) indicates the presence of the determiner for the dominant character, round. In the F_1 generation one of the parents is pure for the character, wrinkled, that is, it carries no determiners for pea shape except those for wrinkled; in like manner, the other parent is pure for the character, round, as it carries only determiners for the round shape. The results of the cross between these two plants is a plant which is a hybrid, that is, it carries determiners for both wrinkledness and roundness. Study the diagrams for the F_2 and F_3 generations as you read the discussion of Mendel's Laws in the context.

carried the determiner for wrinkled to the egg which possessed the determiner for round, and the seed which developed carried the two determiners for the two characters wrinkled (w) and round (R). The character of the seed resulting from the cross may be represented by wR (hybrid), which indicates that both determiners are present.

Mendel found that the hybrid offspring of pure wrinkled (ww) and pure round (RR) parents were all round. He planted these round peas and found that in this second (F_2) generation both wrinkled and round peas were produced, and further that three-fourths of the peas were round and one-fourth were wrinkled. He planted some of the F_2 wrinkled peas and self-pollinated the flowers. Only wrinkled peas developed on these plants. He also planted F_2 round peas and self-pollinated the flowers. In this case one-third of the plants produced only round peas and two-thirds of the plants produced both wrinkled and round peas as in the F_2 generation. These results may be illustrated by diagrams:

Mendel's laws. As a result of this experiment and many similar ones, Mendel came to the conclusion that characters are handed down from parents to offspring in a perfectly definite way.

1. Unit characters. Mendel thought of the plant as made up of distinct and separate characters, as dwarfness, white petals, and smooth seed coat. He called these **unit characters.** In the F_2 generation when wrinkled peas are crossed with round peas, according to our modern way of thinking, cells of the wrinkled pea plants contain a double set of determiners of the wrinkled unit characters or (ww) and their gametes would contain only one or (w). When the wrinkled-round (wR) peas of this same F_2 generation (see Fig. 183) are planted, the hybrid plants produce two kinds of sperm cells, one having determiners of the wrinkled (w) unit character and the other the round (R) unit character. In like manner, corresponding types of eggs would be produced. The different combinations of eggs and sperms are shown in Fig. 183.

In this case one of the zygotes (ww) will produce a plant with only the determiners for wrinkled unit characters in the cells, a second zygote (RR) with only those for the round unit characters, and the other two zygotes (wR) will have determiners for both the wrinkled (w) and round (R) unit characters.

2. Segregation. In the F_2 generation shown in Fig. 183 the two (wR) peas are round, but when the plants from these peas produce gametes, two kinds (w) and (R) are produced, that is, the unit characters are segregated in the production of gametes.

3. Dominance. Referring again to Fig. 183 it is seen that in the F_2 generation three-fourths of the peas are round, although the determiners for the character wrinkled are present in two-thirds of these round peas. For some reason the wrinkled character, although its determiners are present, does not show in the

Fig. 184.—Corn plants showing the Mendelian three-to-one ratio. The seed from which these corn plants grew produced green plants and albino plants without any green color in the Mendelian ratio, albinism being a recessive character.

outward appearance of the seed when the round character is present. Mendel called the kind of character represented by round, **dominant,** and the wrinkled character, **recessive.** Other dominant characters with their recessives in garden peas are yellow seeds—green seeds, colored flowers—white flowers, and tall vines—dwarf vines.

Exercise 136. How do plants inherit the characters of their parents? Corn is suitable material for use in experiments in heredity similar to those of

Mendel. Material for these experiments can be procured from Mr. George S. Carter, Clinton, Conn., and from other dealers in biological supplies.

A. Inheritance of starchiness and sweetness in corn

1. Examine a hybrid F_1 ear of corn resulting from a cross between pure sweet corn and pure starchy corn.

2. Also note the appearance of the ears of the parent stocks. Which is dominant—starchiness or sweetness in corn?

3. Examine an ear of corn grown from seed of an F_1 hybrid plant. Count the starchy grains and the sweet grains. What is the ratio of starchy to sweet?

4. Make a diagram to show the F_1 generation and another to show the F_2 generation. (See Fig. 183.)

5. If you planted the sweet grains, how many different kinds of grains would you get?

6. If you planted the starchy grains, how many kinds of grains would you get?

7. Which would be easier to pick out in pure state, starchy grains or sweet grains?

8. How does this corn illustrate Mendel's Law of Dominance? The Law of Unit Characters? The Law of Segregation?

B. A strain of corn has been developed which carries the albino character as a recessive. That is, in plants from the seed of this strain a part of the plants will appear without chlorophyll. Can a plant without chlorophyll grow to maturity and produce pure albino seed? Explain. Representing the green character by G and the albino character by w, the so-called hybrid plant carrying the determiner for albino would be represented by Gw.

1. How many different kinds of sperms and how many different kinds of eggs does this plant produce?

2. Make a diagram similar to that in Fig. 183 for this corn, showing what occurs when it is self-fertilized. How many different kinds of seed are produced when the zygotes mature?

3. Plant 16 grains of the Gw seed in a pot and determine the ratio of green plants to white plants.

Exercise 137. Why is the Mendelian ratio 1:2:1? It was noted above that in F_2 of the cross between wrinkled peas and round peas the ratio of the different forms of the offspring was 1 RR: 2 Rw: 1 ww. This results from the chance meeting in fertilization of the sperms, R and w, with the eggs, R and w. This may be demonstrated by a simple experiment. Mix in a can 100 red beans and 100 white beans of about the same size. Without looking, remove two beans at a time and place in separate piles the pairs of red beans, the pairs of white beans, and the pairs of red and white beans. When you have removed all the beans from the can, count the number of pairs in each pile. What is the ratio of numbers in each pile? This represents the chance combinations of determiners which result from cross-fertilization. By the law of chance the determiner for red, say of a sperm, is combined with the determiner for red in an egg; the determiner for red in a sperm is combined with the determiner for

white in an egg; and the determiner for white in a sperm will be combined with the determiner for white in an egg. If we let R stand for red and w for white, then the character of the resulting zygotes will be indicated by RR, Rw, and ww.

Construct a diagram to show the chance combinations of this experiment. (Fig. 183.)

FIG. 185.—Different types of leaves on the same branch of scarlet oak. The lower shaded leaves are mesophytic; those above in the sun are xerophytic. These are modifications due to environment and not to heredity.

How do new forms of plants originate? In studying heredity in hybrid plants and their offspring we found that determiners for characters are handed down to offspring in a perfectly definite way. In all our discussion with regard to change in plants due to hybridization we have not accounted for the appearance of new characters which were not present in the ancestry in any visible form. In the year 1699 there was introduced into Holland and England from Sicily a sweet pea species, *Lathyrus odoratus*, the flowers of which were purple and blue in color. In the descendants of this plant there appeared, in 1718, a plant which produced white flowers—and in 1731 another which produced flowers which were pink and white. In the generations which followed, the seeds from the white-flowering plants continued to produce plants which bore only white flowers and the seeds from the pink-and-white flowering plants produced plants with only pink-and-white flowers. From this original plant species there have been produced hundreds of varieties of sweet peas bearing flowers differing in size, form, and color, and in each case the offspring bears flowers like those of its parent; that is, the plants **breed true.**

Any variation in plants, such as those in color, size, and form in sweet peas, which passes from parent to offspring unchanged is known as a **heritable variation.** Dwarfness in the midget sweet pea and in the low-growing nasturtiums is a heritable variation. Variations due to differences in the conditions of the environment, as differences in size and shape of oak leaves on the same tree, are known as **fluctuations.** These variations are not inherited.

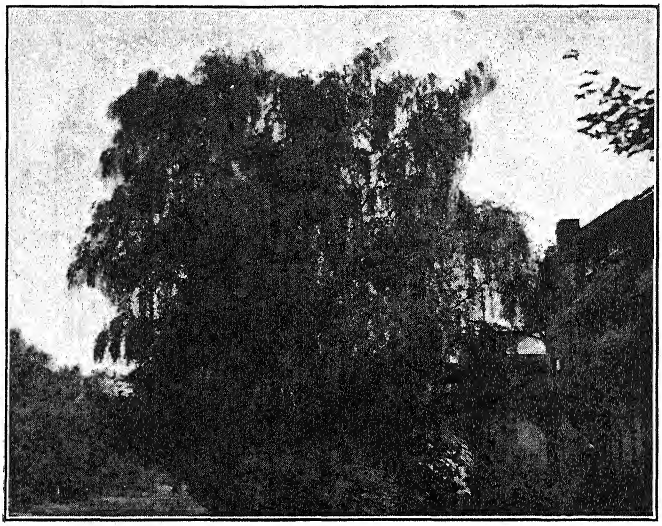

FIG. 186.—The weeping birch is a mutation.

The white sweet pea which appeared from purple-and-blue stock in 1718 and the pink-and-white one that appeared in 1731 from the same parent stock are examples of **mutants** or **mutations.** Mutation has furnished many plants of value to man. From the small currant tomato or love apple of a hundred years ago have developed by mutation many of the varieties of tomato which we know today, some of which produce fruit weighing more than a pound.

Sometimes a branch has appeared which produced fruit or foliage differing in marked degree from that of the main plant. In this way the Boston fern and its many varieties have appeared.

All the improved varieties of the seedless orange have originated from buds. These variations are known as **bud mutations.**

There are reasons for believing that many mutations are taking place in nature. Most of these changes are probably of no advantage to the plant, or they may even prove a disadvantage. These new forms may not be able to compete successfully with other plants of the environment and as a result soon go out of existence. On the other hand, a mutation may be better fitted than its parents to meet the conditions of the environment so that in the struggle for existence it succeeds and may eventually crowd out other plants. This principle is known as **natural selection.** Mutations appear, and they succeed or fail according to whether or not they are able to compete with other plants in their habitat.

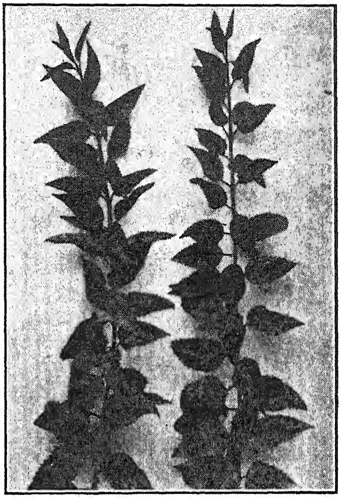

FIG. 187.—The Forsythia branch on the right shows the regular Forsythia habit of bearing two opposite leaves at a node. The branch on the left is a bud mutation from the same plant bearing three leaves at each node.

Exercise 138. How do fluctuating characters differ from hereditary characters? 1. Compare leaves of mulberry which have grown in the sun with leaves from the same tree which were shaded. Note especially size and shape of leaves and their thickness and texture. Make drawings to show differences in size and shape. How do the sun leaves of the mulberry differ from shade leaves? How do you account for the differences?

2. Examine pine needles and leaves of the rubber plant, a xerophytic grass, and *Sedum* or live-forever. Note especially the thickness, leaf surface, and texture of a number of leaves of each kind. Does there seem to be any marked variation between the different pine needles, between the different rubber-plant leaves, between the different grass leaves, or between the different succulent leaves of *Sedum*? Characters like the ones here noted that are handed down from parent to offspring are known as **heritable** characters. Any marked change which is heritable is known as a **mutation.**

Exercise 139. How do new forms of plants originate? A. The common cabbage and a number of other varieties of plants have developed from the

FIG. 188.—Two heads of the red sunflower (at sides) and a head of the ordinary yellow sunflower (center). The red sunflower is a mutation. (Photograph furnished by T. D. A. Cockerell.)

wild cabbage, a native of Europe. From seed catalogues select a list of plants as Brussels sprouts, cauliflower, etc., which have come, or seem likely to have come, from the wild form of cabbage. What part of the plant, as stem, root, flower, is useful to man in each one of the varieties listed?

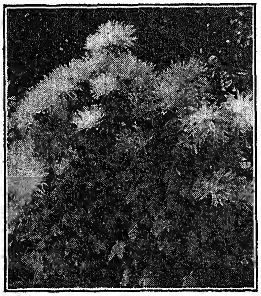

FIG. 189.—Chrysanthemum plant showing bud mutation. This plant of a white-flowering variety produced a branch which bore pink flowers.

B. Make a comparison of characteristics of different varieties of chrysanthemums listed in a flower catalogue of some prominent seedsman. In what ways do these vary from the *Chrysanthemum indicum*, one of the original parents. See Fig. 180.

C. Make a list of vegetables and another of flowers designated as hybrids in the seed catalogues.

D. Make lists of plants which are propagated vegetatively. Which are more apt to come true, plants from seeds or plants from some vegetative part as a tuber or bulb?

Problem 4. How does man develop new kinds of plants?

Many of our most widely cultivated plants have been in the process of development for so many centuries that we know little of their wild ancestors. A small-grained variety of wheat was found among the remains of the lake dwellers in Switzerland which dates from the early stone age.

How have common crop plants originated? **Indian corn** or **maize** is a New World product. When the white man first visited America he found the Indians making use of maize as a crop plant.

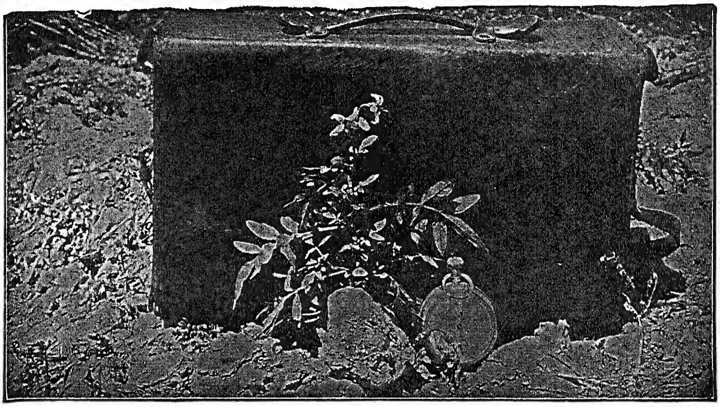

FIG. 190.—The wild potato of southwest United States (*Solanum jamesii*). (After Fitch, Colo. Agr. Exp. Sta., from Robbins, in Botany of Crop Plants.)

We know of no wild form which can be recognized as the immediate ancestor of this important crop plant.

The cultivation of the apple dates back at least as far as that of wheat. The varieties which were used in very early days were small, measuring an inch to an inch and a quarter in diameter. This wonderful fruit seems to be a native of southeastern Europe. The apple was widely distributed in Europe in its uncultivated state, but the fruit was much inferior to that of the cultivated varieties of the present. There are at least five native crabapples in America. These wild apples are fit only for jelly-making and for cooking. The Indians made some use of the wild apple, and when the white man introduced the common apple, they were

quick to take advantage of it. Remains of old Indian orchards still exist in different parts of the country.

You have all enjoyed the luscious fruit of the peach. Have you tasted the fruit of the nectarine? An interesting riddle is connected with the history of these two fruits. The peach is readily recognized by its well-known characteristics, including a downy covering. A peach tree may be producing crops of peaches year after year and all of a sudden it may begin to produce nectarines, similar to the peach but without the downy covering. Afterwards the tree or a part of it may produce either peaches or nectarines. The nectarine is known as a bud sport or bud mutation of the peach. Bud mutations have been responsible for the appearance of some valuable varieties of plants which have been retained by man and propagated by vegetative methods.

The orange belongs to the group of citrus fruits. The wild variety produces fruits which are bitter. The sweet strains have been long in cultivation. The seedless orange arose as a bud mutation; it has been maintained by vegetative propagation and improved by that method and by selection.

The grape of our western coast came from Old World stock; that of eastern United States originated from native species of wild grapes. The more than fifteen hundred varieties of European grapes have all descended from a single species, *Vitis vinifera*, supposed to be native of Asia. The early settlers of America made persistent attempts to establish vineyards of the European grapes in the new country, but without success. The failures were due to an insect pest, *Phylloxera*, a plant louse which infests the roots and to which the European grape was especially susceptible. This pest was later introduced on some nursery stock into Europe where it played havoc with the vineyards. The problem was finally solved. Someone noticed that certain native American species were almost immune to the attack of the phylloxera. Grape vines were started from pieces of vine of these immune plants, then the European *Vitis vinifera* was grafted on these plants. The grapes grown on our Pacific coast are varieties developed from *Vitis vinifera*. Is this method of producing immune grapes vegetative or sexual?

The grapes of the eastern part of the United States have all

been developed from native American species. The original Concord grape vine is still growing in Concord, Massachusetts. It developed as a chance seedling from the native *Labrusca* species, the northern fox grape. Was the method used in producing the Concord grape vegetative or sexual?

How are desirable characters of parent plants combined in offspring? In our discussion of Mendel's law only one set of contrasting characters was considered in the example taken from the

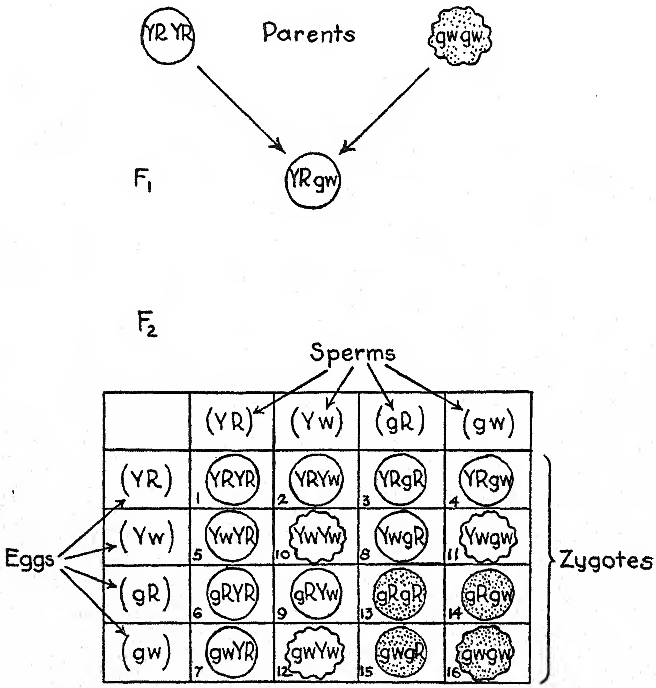

Fig. 191.—Diagram showing the results of self-pollinating a pea plant which carries the determiners for two sets of contrasting characters, in this case, yellow and green, and round and wrinkled (*YgRw*); or of crossing two of the plants. Zygotes 1–9 will produce yellow, round peas, since determiners for the dominant characters, yellow and round, are present in each; 10–12 will produce yellow wrinkled peas, as the determiner for dominant yellow is present, that for dominant round is not present, and that for recessive, wrinkled is present. Why will 13–15 produce green, round peas, and 16 green, wrinkled peas?

experiment with peas. These characters were round and wrinkled. If now we take a second pair of contrasting characters into our experiment the situation becomes much more complex.

The characters actually chosen by Mendel in one set of experiments with peas were yellow-round and green-wrinkled; that is, one of the parent plants selected produced peas which were yellow and round, and the other plant produced peas all of which were green and wrinkled (Fig. 191.) In this case when the plants were cross-pollinated, one set of gametes, say the sperms, carried determiners for yellow and round and the other set of gametes, the eggs, carried the determiners for green and wrinkled. The zygote which resulted from the union of these two gametes contained the determiners for yellow, round, green, and wrinkled. Since yellow is dominant over green, and round over wrinkled, the peas of this F_1 generation were all yellow and round in character.

In Mendel's experiment the seeds of this F_1 generation were planted and the cells of the hybrid plants which resulted all contained the determiners for the characters yellow, round, green, and wrinkled, and when these plants produced gametes, combinations of determiners present were as follows: YR, Yw, gR, and gw. The table (Fig. 191) shows the different possible zygotes. Since yellow and round are dominant over green and wrinkled, these characters, when their determiners are present, will show in the peas produced regardless of whether or not the determiners for green and wrinkled are present.

It is seen, then, that in general, out of every sixteen **dihybrids** resulting from this cross, nine were yellow and round, three green and round, three yellow and wrinkled, and one green and wrinkled. The characters of the parents for color and nature of seed coat were combined in different ways in different individuals. The keen eye of the practical plant breeder is able to select from thousands of hybrids the individual plant which may have the desired combination of characters.

If the selected specimen is a potato or fruit or other plant which may be propagated by vegetative means, the offspring will all have the desired combination of characters. If, on the other hand, the plant can be propagated only from seed, certain offspring of the dihybrid will show the desired combination of characters,

but other combinations of characters will also appear in others of the offspring.

Suppose we desire the combination, yellow-wrinkled in our plant. We select only yellow wrinkled seeds. Seeds *YwYw*, of course, will produce only plants which bear yellow wrinkled peas.

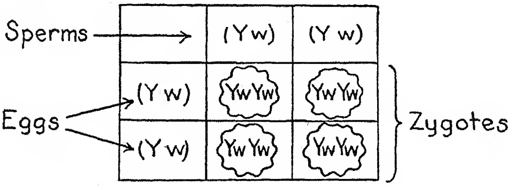

FIG. 192.—Results of self-pollination of a plant from the *YwYw* zygote. All of the offspring are pure yellow wrinkled like the parent.

But some of the yellow wrinkled seeds are of the *Ywgw* kind. If the *Ywgw* seeds are planted, some of the peas which result will be green-wrinkled. However, by continued selection and isolation—that is, by **pedigree culture**—it is often possible to secure dihybrids which will breed true with respect to the desired combination of characters.

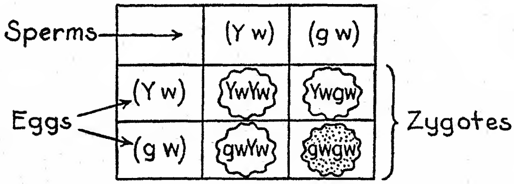

FIG. 193.—Results of self-pollination of a plant or crossing two plants from the *Ywgw* zygotes. $\frac{1}{4}$ of the offspring are pure yellow wrinkled (*YwYw*); $\frac{1}{4}$ are pure green wrinkled (*gwgw*); and $\frac{1}{2}$ are yellow wrinkled (*Ywgu*), but, like the parent, are not pure.

In the same way trihybrids may have the combination of three desired characters from parents which differ from one another in three respects.

The highly developed technique of Burbank made it possible for him to produce a trihybrid, Burbank's shasta daisy, in which he secured a combination of characters belonging to three distinct

parent stocks, American, English, and Japanese. The American daisy, or marguerite, is a very free bloomer, but it has a sprawling habit and unattractive leaves. The English plant is attractive and sturdy and with handsome leaves. The Japanese type has attractive lustrous flowers. Burbank's attempt to combine in one plant all the desirable features of the three resulted in the shasta daisy.

What methods has man used in the improvement of plants? The most common method of plant improvement is the continuous selection of the best for seed. This can be illustrated by the practice of any practical corn-grower who goes into the field of mature corn and picks seed for the next crop. He selects for certain characters, as desirable stalk growth, long kernels, ears well filled out to the tip, and earliness of maturity. In this way an artificial selection of the best is made generation after generation. This method, known as **mass selection,** is effective in improvement, but not for originating new forms.

The more recent method of plant improvement was that which was introduced by Gregor Mendel in 1865 and which came into general use in the study of heredity and plant improvement thirty years later as the science of genetics. This method is known as **pedigree culture**. Whereas mass selection secures a good average plant, pedigree culture is concerned with the selection of the individual plant with a view to the development of a superior plant strain. This is the method used in the development of strains of plants which are drought-resistant or disease-resistant or resistant to damage by frost.

Thirty-five years ago, a very destructive chestnut bark disease was introduced into America on nursery stock. The American chestnut is threatened with extinction from the ravages of this disease, as it is especially susceptible. It has been found that a Japanese species and also a Chinese species of chestnut are resistant to the attack of the disease. Since the European as well as the American species of chestnut is susceptible, the future of the chestnut in the world rests with the use and improvement of the **resistant strains** by hydridization. In fact, a resistant strain has been produced already by crossing the American bush *Chinquapin* with the Japanese variety of chestnut.

Pedigree culture is illustrated also by the development of a watermelon resistant to the destructive wilt disease. The citron *Citrullus vulgaris* is immune to wilt but inedible. The Eden watermelon is edible, but susceptible to wilt. The two were crossed, producing in the first generation hybrids of wonderful vigor and productiveness. The second generation was extremely variable, the citron characters appearing to be dominant. From 4000 plants, ten fruits were selected. Seeds of these were planted,

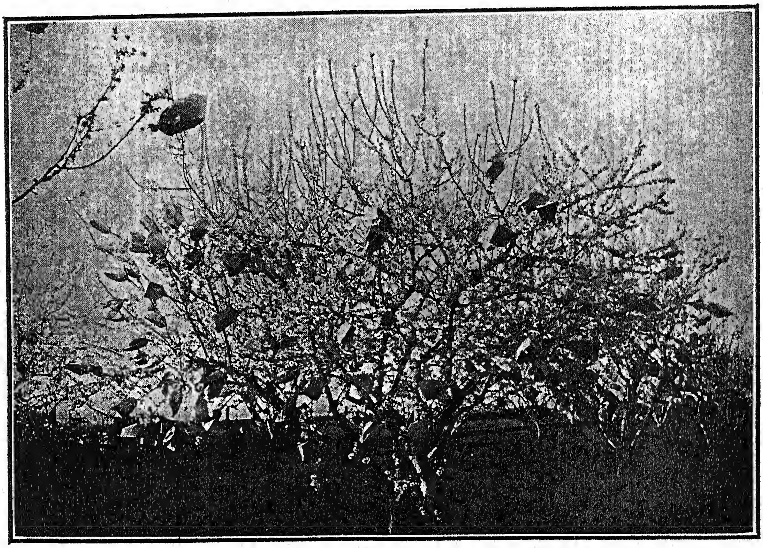

FIG. 194.—Artificial pollination. The flowers to be cross-pollinated are emasculated, and then kept covered with a bag until the pistils are pollinated and the stigmas have passed the receptive stage. (From Division of Pomology, College of Agriculture, University of California.)

and after five years of selection the desired melon, combining wilt resistance and edibility, was secured.

The characteristic noted in the F_1 hybrid melons is known as **hybrid vigor.** Frequently the hybrids resulting from a cross between two strains show marked increase in vigor and productiveness over those of either parent. Burbank made use of the phenomenon of hybrid vigor in the production of a new walnut

tree by crossing the English walnut with the California black walnut. The hybrid which resulted grew in 14 years to be 75 feet tall and to have a trunk 2 feet in diameter while a tree of the black walnut parent type grew a trunk only 6 or 8 inches in diameter and attained a height of only 20 feet in 31 years.

Suggested activities. 1. Write a summary of the history of some fruit, as the Delicious or Jonathan apple.

2. Write a review of a book describing the work of Luther Burbank.

3. Write a paper on the importance of the work of Gregor Mendel.

ADDITIONAL QUESTIONS AND EXERCISES

1. What reasons have we for thinking that the earliest forms of life on the earth were plants?
2. Why is it more likely that the earliest plants lived in water than that they lived on land?
3. In what ways did plants change in form in changing from a water habitat to a land habitat?
4. What is a fossil plant?
5. In what different ways are fossils formed?
6. It is known that limestone was formed at the bottom of the sea. How can you explain the fact that great limestone deposits are found at present far inland?
7. If you have visited a "petrified forest" prepare a report to be read to the class describing what you saw.
8. Under what conditions could mineral deposits take the place of the wood and form the so-called petrified wood?
9. How do you explain the fact that we find fossils of plants which are different from any plants now living?
10. How can you explain the fact that fossils of tropical plants are found in regions which now have a temperate climate?
11. Explain the fact that vast coal deposits are found in Alaska.
12. Which plant species are more likely to change with a changing environment, those which reproduce only by vegetative methods or those which reproduce sexually? Explain.
13. Explain why the two daughter cells resulting from simple cell division are similar and also similar to the mother cell.
14. How does a knowledge of Mendel's Laws of Heredity help man in producing improved varieties of plants?
15. How does a farmer use mass selection in selecting seed corn from his fields?

UNIT IX

THE CLASSIFICATION OF PLANTS

We learned in the last unit that during past geologic times the character of the plant life of the earth has changed; that in the course of time certain species of plants have become extinct; that new species have come into existence; that there has been constant change. Scientists are convinced that the present is the offspring of the past; that the plants which populate the earth today have characteristics like those of the past, because they are offspring of plants of the past. But it appears that, although there has been increasing change for centuries and centuries, certain plants in existence today resemble very remarkably those of early geologic times. We refer particularly to such aquatic plants as the algae (pond scums, seaweeds). Undoubtedly, the reason for this lack of change of such plants is that water is a uniform environment, subject to very little change in temperature, in oxygen and carbon dioxide content, and in its mineral composition. Water of the earth has been very much the same throughout geologic history. Consequently, the plants of water have not undergone much change during that time. Land environments, on the other hand, are extremely variable. Different types of soil, varying in texture, in chemical composition, in exposure to the sun's rays, in temperature, in water-holding capacity, present different sets of conditions under which plants must grow. And we find that the kinds of plants which grow under these different conditions are quite dissimilar. We are forced to the conclusion that differences in environmental conditions have been responsible for inducing the changes which have occurred in plants. So today we find on the earth's surface a great assemblage of plants differing greatly in their form and structure and habits of growth, populating all types of environments—salt water, fresh

water, cold water, hot water, sandy soils, clay soils, lime soils, humus soils, wet soils, dry soils, rocky exposures, arctic and alpine regions, tropics, and so on. And these plants grow under the particular set of conditions they do because they have structures and habits of growth which adapt them to these conditions.

There is strong evidence that life as we know it on this earth originated in the water. The first forms of animals and plants were water forms. Water plants very similar, probably, to certain simple algae found in the waters of the earth today were the ancestors of our present-day plants, both of the water and of the land. As the surface of the earth changed, as climates changed, new kinds of plants came into being. But these new kinds resembled their parents; and, too, they differed from their parents. Slight modifications in form or behavior may have enabled certain offspring to live and reproduce under slightly different conditions from those to which their parents were accustomed. After many, many generations the individuals may come to be very unlike their ancestors of ages past.

All plants have much in common. This is one reason we regard them as related. Pond scums, molds, mildews, mosses, ferns, pines, roses, potatoes, oaks, and wheat—all have certain very definite characteristics which indicate a common ancestry.

Their cell structure is the same; the living stuff, protoplasm, is essentially similar; they respire, nourish their bodies with the same kinds of food, digest food, and reproduce in very much the same manner. Living things which have so many likenesses in their fundamental structures and processes, even though they may look unlike, must certainly be related.

Problem 1. How are plants classified?

There are some 250,000 different kinds of plants in the world. We call these different kinds **species**. We recognize different degrees of relationship among them. For example, we recognize that different kinds of oaks are more closely related to each other than are oaks to maples. It is likely, we would assume, that apples and pears are closer "kinfolks" than are apples and wheat. And it would be safe to say that the different kinds of flowering

plants are more closely allied than are flowering plants and mushrooms.

From the earliest times man has attempted to classify plants, just as he has attempted to classify all sorts of things, even his ideas. One of the early attempts to classify the common plants about us, before the days of the microscope and the detailed knowledge of plant structure, was based upon habit of growth. This was a classification into three large groups, namely **trees, shrubs,** and **herbs.** This was a sort of artificial or arbitrary system of classification. Study revealed the fact that bamboo (a tree) and corn (an herb) were really more closely related than bamboo and cottonwood, both trees; and, as another example, the strawberry (an herb) is more closely allied to the rose (a shrub) than are roses and sagebrush (both shrubs). The reader will readily think of other examples. An attempt has been made in grouping plants to place together those with fundamental likenesses; with similarities in structure which represent true relationships. The student readily understands that frogs, grasshoppers, and kangaroos are not placed in the same natural group just because hopping about is common to them. The body form, methods of reproduction, and all life habits are very greatly different. But frogs and toads are closely related; kangaroos and opossums are closely allied; and grasshoppers and locusts are very much alike.

What then are the characters, among plants, which express true affinities? How do we tell that one plant is near in its relationship to another? Is it the kind of root system they have? Is it the sort of stem they have? Is it the kind of environment in which they live? None of these. Scientists have learned to place reliance in **reproductive structures and behavior as marks of true relationship.** For example, beans, peas, clover, alfalfa, and peanuts are naturally grouped together because the flowers (reproductive structures) are built on the same general plan; goldenrods, chrysanthemums, daisies, sunflowers, and thistles are grouped together also because of very similar floral structure.

Space will not permit a discussion of the various systems of classification of plants which have been proposed during the last several centuries. Suffice it to say that one system has replaced

another as new facts about the plants of the world have come to light; and that system is considered most perfect which most accurately expresses the true affinities of plants.

Problem 2. What are the four great groups of plants?

One modern system of classification which has been widely accepted would throw all plants of the world into four large groups, called phyla or grand divisions. These four large groups are as follows:

1. **Thallus plants (thallophytes),** such as the pond scums, seaweeds, bacteria, molds, mildews, yeasts, rusts, smuts, mushrooms, and toadstools. The plants belonging to this large group have no roots, stems, or leaves in the ordinary sense; they have no flowers, the reproductive organs and methods of reproduction being very simple. Certain thallus plants are regarded as simple and primitive, that is, the first kind of plants to appear on the earth; in fact, they are believed to be the progenitors of more complex plants.

2. **Mosses and liverworts (bryophytes).** These are well-known plants growing in moist places. Usually, they are close to the soil, that is, in contact with a source of water. No part of the plant is very far away from the soil, and hence there is very little need in the plant for water-conductive tissue. However, moss leaves have strands of long cells which may serve as channels of water movement, but such channels never reach the degree of specialization that they do in trees and shrubs. Mosses and liverworts are regarded as being more advanced than thallus plants. Not only have they more complex vegetative structures, but also the methods of reproduction are more highly specialized.

3. **Ferns, horsetails, and club mosses (pteridophytes).** This is a large assemblage of plants which have structures enabling them to live on the land, and bring their leaves up in the air, distant from the immediate source of water—the soil. In order to do this there must be in the stems and leaves a certain amount of strengthening tissue, and also special conductive tissue for the rapid movement of water, mineral salts, and foods. This group of plants—the pteridophytes—includes the first vascular plants,

that is, plants with vascular bundles. As stated, mosses and liverworts do not have vascular bundles. In this particular, as in methods of reproduction, they are more primitive than pteridophytes. None of the thallophytes, bryophytes, or pteridophytes have seeds.

4. Seed plants (spermatophytes). Of the four large groups of plants, this one has the greatest number of species, and has most successfully occupied the surface of the earth. The one outstanding characteristic of the group is the **seed-bearing habit.** The seed is essentially a young embryo plant, in a dormant state, surrounded by protective coats, and accompanied by a reserve of food. Thus, the young plant in the seed may live for years. Moreover, seeds often have devices, such as wings, barbs, prickles, etc., which facilitate their spread over the earth's surface. In addition to the seed-bearing habit, members of this group have developed extensive vascular systems, and strengthening tissues, enabling them to attain great heights, as witness the tall trees of the forests.

Problem 3. How are the seed plants classified?

Each of the four large groups of plants, briefly described above, is divided into subgroups, and these in turn into smaller groups, and so on. As an illustration, let us consider a seed plant, such as common wheat. Wheat belongs to the grand division of the plant kingdom known as the spermatophytes. It is a seed plant. Among seed plants there are **two** very distinct subgroups, which we will call **classes.** There are those seed plants, such as pines, spruces, firs, cedars, etc., which do not bear flowers, as we ordinarily understand that term, and which have **naked seeds,** that is, seeds without any surrounding covering except the seed coats. This class is called **gymnosperms.** And there are those seed plants which have flowers, and seeds borne in a case, such that at some part of its life the seed or seeds have a surrounding covering in addition to the seed coat. This class is called **angiosperms.** Common wheat falls into this second class. It is an angiosperm. But the angiosperms is a very large group of plants. Study of large numbers of plants belonging to the

group has shown that all of them fall naturally within two subclasses. In one subclass, the so-called **monocotyledons**, there is but **one seed-leaf or cotyledon in** the embryo and seedling; in the other subclass, the so-called **dicotyledons**, there are **two seed-leaves or cotyledons** in the embryo and seedling. Common wheat is a monocotyledon. This subclass of plants, as all other subclasses, is subdivided into smaller groups, called **orders**. For example, wheat belongs to the order *Graminales*, one including

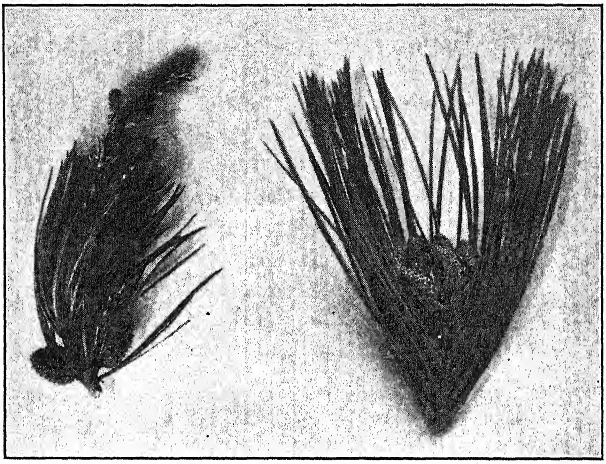

FIG. 195.—First-year and second-year carpellate cones of pine (left), and staminate cones (right).

all grasses and sedges. The plants belonging to this order have certain outstanding characteristics, such as a large supply of food stored in the seed, and inconspicuous flowers with surrounding scales, and no petals or sepals. All orders of plants are subdivided into families. An order may possess few or many families. For example, the order Graminales has but two families, *Gramineae* (grasses), and *Cyperaceae* (sedges, rushes, etc.). Wheat is a grass (family *Gramineae*). All plant families are subdivided into **genera** (singular, **genus**). For example, in the grass family there are such common genera as *Triticum* (wheat), *Avena* (oats),

Hordeum (barley), *Zea* (corn), etc. As a rule, in any genus of plants there are a number of different *species*. Common bread wheat is *Triticum aestivum*; Polish wheat is *Triticum polonicum*; durum wheat is *Triticum durum*; etc. So, in the system of classifying plants now in use, the common bread wheat is a plant which has characteristics such as to place it in the genus *Triticum*, which in turn is a member of the grass family (*Gramineae*); this belongs to the grass order (*Graminales*); this, one of the orders of the larger groups, belongs to the subclass, monocotyledons; this, in turn, belongs to one of the subdivisions of the class angiosperms, or flowering plants; and this class belongs to the grand division, spermatophytes.

The system of classifying as applied to common wheat may be shown in diagram form as follows:

Grand Division—Spermatophytes
  Class—Angiosperms
    Subclass—Monocotyledons
      Order—Graminales
        Family—Gramineae
          Genus—Triticum
            Species—aestivum

Problem 4. What is a scientific name?

In giving the **scientific name** of bread wheat, for example, we use both the generic and specific names: *Triticum aestivum*. *Triticum aestivum* is a **binomial**; that is, it consists of two names, *Triticum* and *aestivum*. *Triticum*, alone, refers to all kinds of wheat. *Triticum* is the genus to which all wheats belong. A certain kind or species of wheat, the common bread wheat, having certain well-defined characteristics, is called *Triticum aestivum*, *aestivum* being the specific name. However, *aestivum* alone means nothing; it must be joined with the name of a genus in order to refer definitely to a certain kind of plant.

Every known different kind of plant in the world has been given a scientific name which is the same in all languages. Common names vary from country to country. For example, whereas

the English know the great bread cereal as **wheat**, the Germans call it **Weizen**, the French **blé**, etc.; but the world over in scientific language it is *Triticum aestivum.* From the scientific standpoint the advantage of this is apparent. If one looks through any nursery or seed catalogue, he will note that reference is made to many plants, not only by their common names, but by their scientific names as well.

Whenever a **new species** of plant is discovered somewhere in the world, some botanist (systematic botanist), usually a specialist in the group to which the plant belongs, writes a description of it, and gives it a name. This description and name are published in some one of the many scientific journals of the world, and the specimen from which the description was made constitutes a **type specimen** and is filed in some herbarium. It should be stated that, of the hundreds of thousands of different species of plants known to man, there exists somewhere in published form a description of each. The individual who describes a new species places after it his name or an abbreviation of his name. For example, when we see the scientific name of common oats written *Avena sativa* L., we know that the " L." is the abbreviation for **Linnaeus**, an early Swedish botanist, who first described common oats.

Suggested activity. Using a plant manual or nursery catalogue, record the scientific names of 20 common plants. Find out from an unabridged dictionary the derivation and meaning of the specific names. Are they descriptive of some character of the plant, or of its habitat, or of its distribution?

Problem 5. What do we mean when we speak of " simple plants " and " complex plants "?

Bacteria and blue-green algae are among the simplest of plants because their whole body consists merely of a single cell, or groups of similar cells. There are no special organs to perform this and that function. All the activities of the plant body are carried on in the single cell. Moreover, the cells themselves are simple in structure, in that they have no definite nucleus, no plastids, and but few special and definite cellular structures. We would regard the plant body of *Spirogyra*, for example, as

more complex than that of a blue-green alga or a bacterium. In each *Spirogyra* cell there is a definite nucleus and a well-defined plastid or plastids, and the cells that are joined end to end to make up the plant body do not all behave alike, for some of them form reproductive bodies, whereas others do not. Thus, there is within the *Spirogyra* plant body some **differentiation**, which leads us to believe that *Spirogyra* is a more complex plant than any of the blue-green algae. In still so-called higher, that is, more complex, algae, there are special cells which act as hold-fasts, others which produce male reproductive organs, others which may act as protective organs. Thus there is further differentiation or increase in complexity.

Fig. 196.—The orchid is one of the most advanced of the flowering plants.

As another illustration of the difference in the complexity and degree of advancement of plants, let us consider flowering plants. Now, there is no evidence that all the known kinds of flowering plants in the world today came into existence at any one time. Quite the reverse is true. There were flowering plants with characters that we regard as "primitive," and geologic record lends evidence that such plants appeared on the surface of the earth earlier in time than the more "advanced" kinds. Moreover, these "primitive" flowering plants are the ancestors of those which came after them. Primitive flowering plants, for the most part, had flowers with separate carpels with superior ovary, with numerous stamens, with regular symmetry, and with separate petals. The ordinary buttercup is a flower of this type. As time passed, and development among flowering plants took place, it is evident from a many-angled study that there were certain tendencies in the development of flowering plants; the

direction of development was along rather definite lines. For example, there was a tendency for development from separate carpels to united carpels; from separate petals to united petals; from regular flowers to irregular flowers; from numerous stamens to a definite number of stamens (usually less than ten); and from a superior ovary to an inferior ovary. The harebell has all the "advanced" characteristics just noted, and for those reasons would be considered a type of flower which has progressed farther in its development and degree of complexity than the buttercup. There are many other tendencies besides those mentioned which enable us to judge of the relative complexity or advancement of flowering plants. For example, wind pollination is usually associated with more primitive flower types than is insect pollination.

So, as botanists have studied the great array of different flowering plants which populate the earth, they have attempted, after thorough study of all their characteristics, to place them in groups and subgroups which show their actual affinities, or relationships, or degree of advancement. In other words, botanists have attempted the construction of natural systems of classification. For example, the arrangement of different flowering plants into certain classes, orders, families, genera, and species is by no means an arbitrary one, made for man's convenience, but the particular arrangement adopted is one which conforms to the natural relationships of the plants considered.

Suggested activities. 1. Grow different kinds of algae in the laboratory or at home. Much can be learned of the nature of these simple plants by setting up suitable conditions and growing the plants indoors. Collect pieces of bark showing a green coating of *Protococcus* from the north side of trees in the woods. Place the pieces of bark, green side up, in a soup dish, moisten, and cover with a pane of glass. The light conditions of a north window are suitable. Moderate temperature and light conditions and moist air are necessary for the growth of the *Protococcus* on the pieces of bark. Scrape a small amount of the green material and mount in water under a cover-glass. Examine with the low and high power of the microscope. What characteristics place *Protococcus* in the thallophyte group?

Collect green masses of plant material found floating free or attached to sticks and stones in streams or ponds. Arrange jars in moderate light in the laboratory, and place in separate jars a small quantity of each specimen of alga with water from the pond or stream in which it was found growing. Cover each jar with a pane of glass and let it stand for observation. What character-

istics do you observe without or with the aid of the microscope which place these algae in the thallophyte phylum?

2. Make a collection of dry fungi and arrange as a laboratory demonstration.

3. Grow mosses in the laboratory or at home. Make a collection of various kinds of mosses, and arrange growing conditions for them as follows: Place in a glass aquarium 2 inches of rich woods soil and over this arrange the different mosses which you have collected. Moisten the soil and mosses well and cover with a pane of glass. A north window affords suitable light for most mosses. Note the characteristics which place mosses in the Bryophyta.

4. Make a collection of small fern plants and establish a fernery in the manner described above for the mosses.

5. Prepare a laboratory or class demonstration of an entire fern plant showing spore-bearing and other fronds, underground stem, and roots. Why does the fern belong to the pteridophyte group?

6. Make a collection of seeds of dicotyledons, as bean, pumpkin, and cucumber.

7. Make a collection of seeds of grasses (monocotyledons), as corn, oats, and wheat.

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Flowers and Flowering Plants, by Raymond J. Pool, published by McGraw-Hill Book Company, New York, 1929. 378 pages, 191 illustrations. An introduction to the nature and work of flowers and the classification of flowering plants.

UNIT X

THE ECONOMIC IMPORTANCE OF PLANTS TO MAN

We have learned that **all animal life on the earth, including man, is dependent upon green plants.** Green plants are the only organisms on this earth which possess the power of converting the energy of light into food. All non-green plants and all animals derive their food directly or indirectly from green plants. Thus,

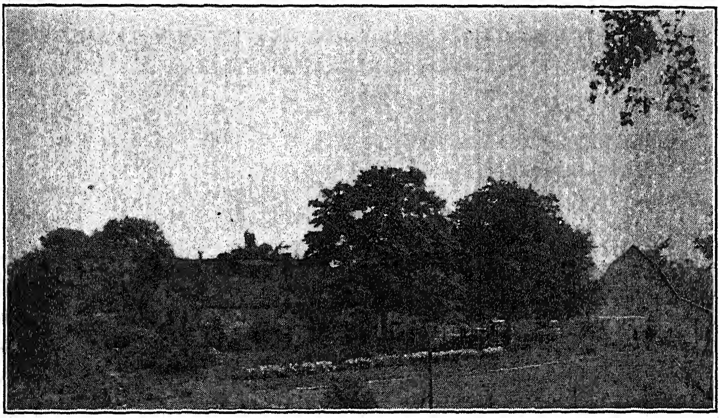

FIG. 197.—Trees and other plants help to make this country place a real farm home.

the very life of man on the earth depends upon the activity of green plants.

The great civilizations of the world have developed where natural conditions favored the cultivation of certain food plants, chiefly cereals. **Rice, wheat, corn**—these have been the three most important food plants which have made possible the development of three great civilizations: (1) that which spread over eastern Asia, Japan, the Indian Archipelago, the Malay Peninsula, and

the Philippine Islands was dominated by rice; (2) that which developed in western Asia, northern Africa, and Europe had wheat and related cereals as its chief food plants; and (3) the physical, social and religious life of the Mayas, Aztecs, Incas, Guatemalans, Peruvians, and other aboriginal American peoples was based on maize or Indian corn.

The plants of economic importance to man fall into two large groups, namely, (1) those that are useful, and (2) those that are harmful, or interfere with man's operations. The number of products of plant origin is enormous; those useful to man in one way or another may be grouped as follows: foods; industrial plants including wood, coal, cork, fiber, resins, and turpentine, gums, plant dyes, fixed and volatile oils, and rubber; medicinal plants; and ornamentals. Those plants which interfere with man's operations include weeds, poisonous plants, hay-fever plants, and those which cause plant and animal diseases.

Problem 1. What are the principal food plants of the world?

The principal food plants of the world include the cereals, fruits, nuts, vegetables, beverage plants, sugar plants, and spices.

Cereals. The principal cereals are wheat, oats, barley, rye, rice, corn (maize), sorghums, millets, and buckwheat. All the cereals, with the exception of buckwheat, belong to the grass family (Gramineae). A cereal is a grass grown for its grain. The great importance of cereals is due to the fact that a large reserve of food is stored in the seed. Starch is the chief food reserve of such seeds.

By far the largest proportion of the world's supply of flour is made from wheat. There are a number of economic types of wheat, chief of which are common bread wheat, durum, club, and emmer. Durum wheats are used extensively in the manufacture of macaroni, spaghetti, and semolina. Emmer is used as a feed for livestock, and to some extent in the manufacture of breakfast food. Common bread wheat and club wheat are the ones ordinarily used for flour. Oats are consumed in large amounts in the form of rolled oats or oatmeal. It is also valued as horse feed. Barley has a great variety of uses: preparation of malt, flour, cereal breakfast foods, stock feed, and hay. Rye flour is made into

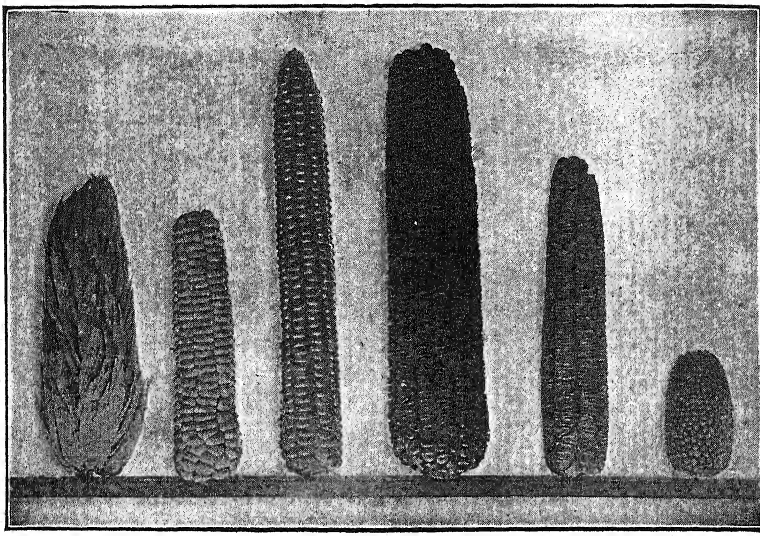

FIG. 198.—The six principal types of corn. From left to right, pod corn, soft corn, flint corn, dent corn, sweet corn, and pop corn. (After Montgomery, from Robbins, in Botany of Crop Plants.)

bread; the grain is fed to stock; the straw finds considerable use in the manufacture of paper strawboard, hats, and other coarse

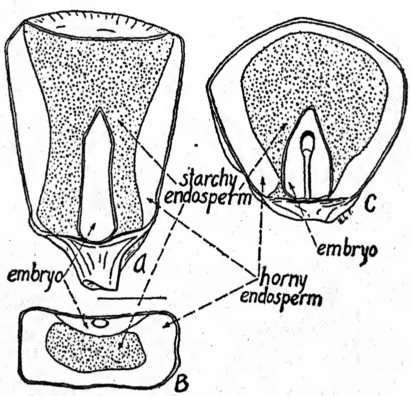

FIG. 199.—Grain of corn. A, median lengthwise section, cut parallel to broad surface, of grain of dent corn; B, cross-section of the same through the embryo; C, section as in A of flint corn. (From Robbins, in Botany of Crop Plants.)

straw articles. No other cereal is put to such a variety of uses as is corn. The grain and fodder are both valued stock feed; in addition, there are such products as corn meal, cornflakes, starch, glucose, etc. There are two types of sorghum, the sweet sorghums

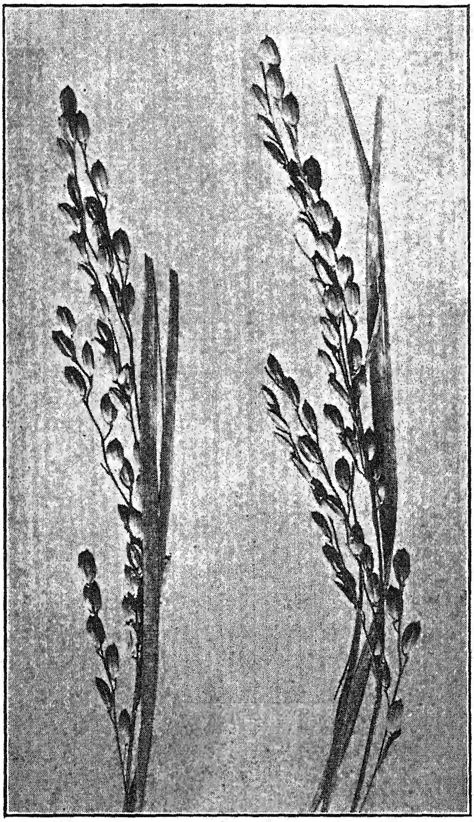

FIG. 200.—Panicle of rice (*Oryza sativa*). (From Robbins, in Botany of Crop Plants.)

from which a syrup is made, and the non-saccharine or grain sorghums, some of which are raised for the grain and others from which brooms are made, utilizing the flower stalks. Rice is a food for more human beings than any other grain. The millets are grown

chiefly as a hay crop, for pasturage purposes, and for the seeds. The principal use of buckwheat is in the manufacture of pancake flour.

Suggested activities.

1. Locate on an outline map of the United States the principal corn-growing regions and the principal wheat-growing regions.
2. Prepare a paper on the manufacture of brooms.
3. Prepare a report on the milling of rice.

QUESTIONS

1. What are the differences between " soft wheat " and " hard wheat "?
2. What is the " gluten " of wheat?
3. What is " bran " of wheat?
4. What are the differences between graham, entire wheat, and patent or straight bread flour?
5. What is meant by spring wheat? Winter wheat?
6. What is the relation between " wild oats " and ordinary cultivated oats?
7. What is the corn silk? The corn tassel?
8. How do you explain the occurrence of different colored grains on an ear of corn?

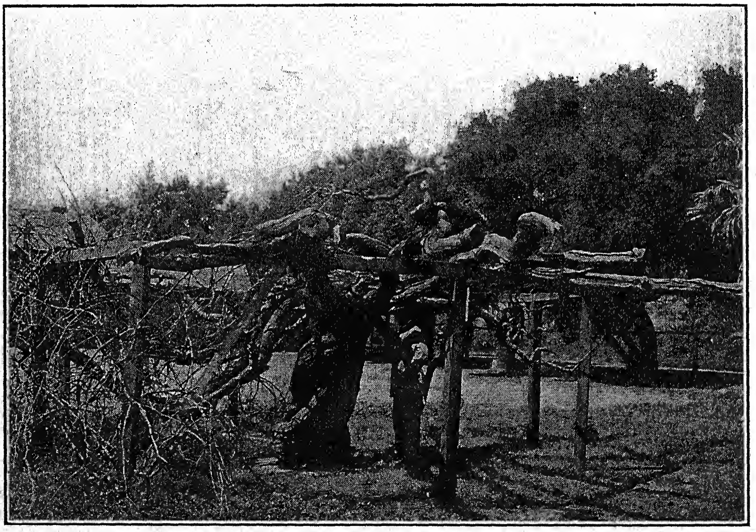

Fig. 201.—A very old grape vine, in Carpenteria, California. (Photograph furnished by Division of Pomology, California College of Agriculture.)

9. What are the differences between popcorn and other types of corn? Account for the popping qualities of the former.

10. What are the qualifications of a good malt barley?

11. Name five important breakfast foods and the cereals from which they are made.

Fruits. In a popular sense a "fruit" is a juicy structure eaten chiefly for its sweet or acid juice. This is the sense in which it is used here. Strictly speaking, a fruit is the matured ovary of a

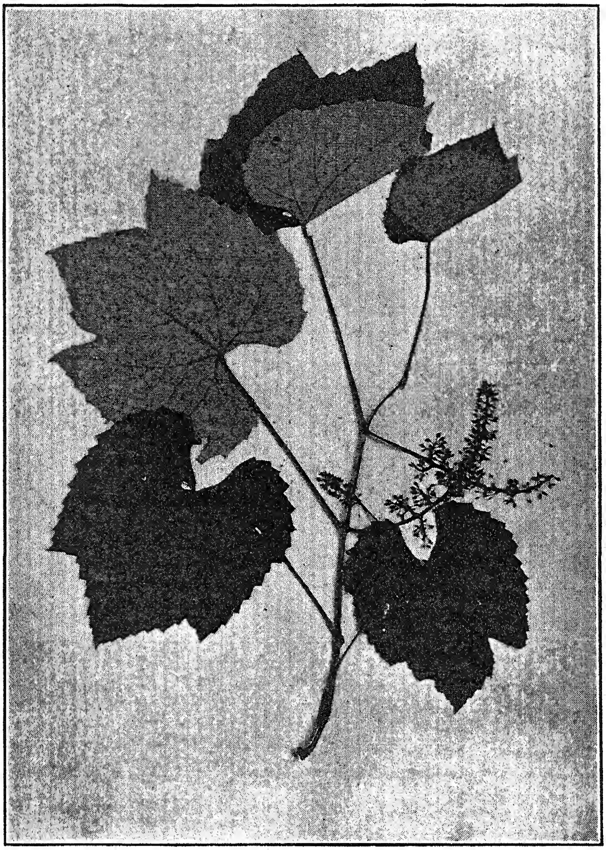

FIG. 202.—Northern fox grape, *Vitis labrusca*; leafy flowering stem. (From Robbins, in Botany of Crop Plants.)

flower and, in some instances, other flower parts. Used in this sense, it would include grains, nuts, and such common " vegetables " as peas, beans, squash, etc.

In temperate climates the more common fruits are found in the following plant families: palm family (date); mulberry family (mulberry, fig); gooseberry family (gooseberry, currant); rose family (raspberry, blackberry, dewberry, strawberry); apple

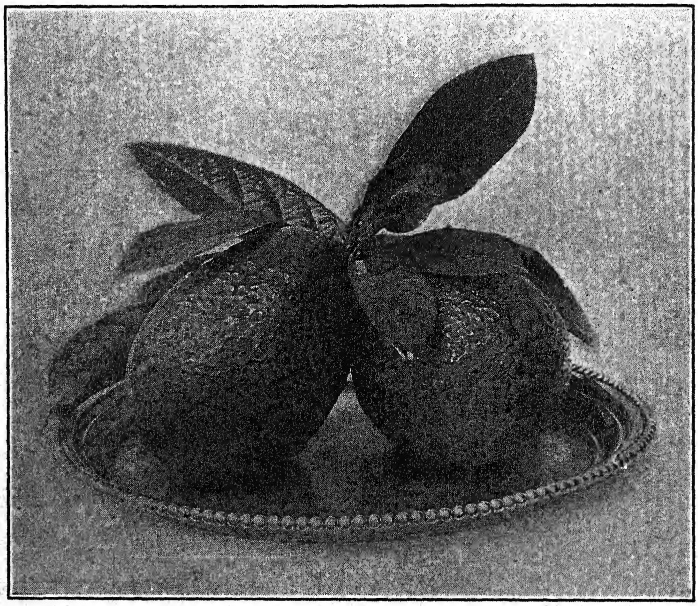

FIG. 203.—Meserve Avocado grown at Long Beach, California. (Photograph, courtesy of Professor Ira J. Condit, University of California Branch of the College of Agriculture at Los Angeles. (From Robbins and Ramaley, in Plants Useful to Man.)

family (apple, pear, quince); plum family (plum, cherry, apricot, peach, nectarine); citrus family (kumquat, orange, lemon, grapefruit, lime); grape family (grape); potato family (tomato); cucurbit family (watermelon, muskmelon); olive family (olive).

The tropics produce a great many edible fruits. Chief of them are the banana, pineapple, mango, avocado, and papaya.

Others of less importance, at least to us in temperate climates, are the cherimoya, sugar apple, soursop, loquat, guava, Japanese persimmon, and mangosteen.

QUESTIONS

1. In southwestern United States, where the date palm is grown, it is usually propagated by the offshoots rather than the seeds. Explain why this is the practice.
2. What is the relation of the mulberry tree to the silk industry?

FIG. 204.—Date palms, *Phoenix dactylifera*. Garden of Deglet Noor dates in full bearing, southern California. (After Nixon, from Robbins, in Botany of Crop Plants.)

3. In order to grow Smyrna figs it is necessary to introduce into the orchard the fig wasp. Explain.
4. What are the differences between currants and gooseberries?
5. How does the blackberry fruit differ from that of the raspberry?
6. What is the loganberry?
7. How is vinegar made from apples?
8. What is a prune?
9. What is the relation of the nectarine to the peach?
10. What is the difference between a peach and a nectarine?
11. What is commercial " citron "?

Nuts. The nut is a fruit, botanically speaking. It is eaten for the edible kernel which is usually protected by a hard shell. Nuts are rich in protein and oil. The principal nut-bearing families are as follows: walnut family (walnut, butternut, pecan and hickory nut); birch family (filbert or hazelnut); beech or oak family (chestnut); plum family (almond); pea family

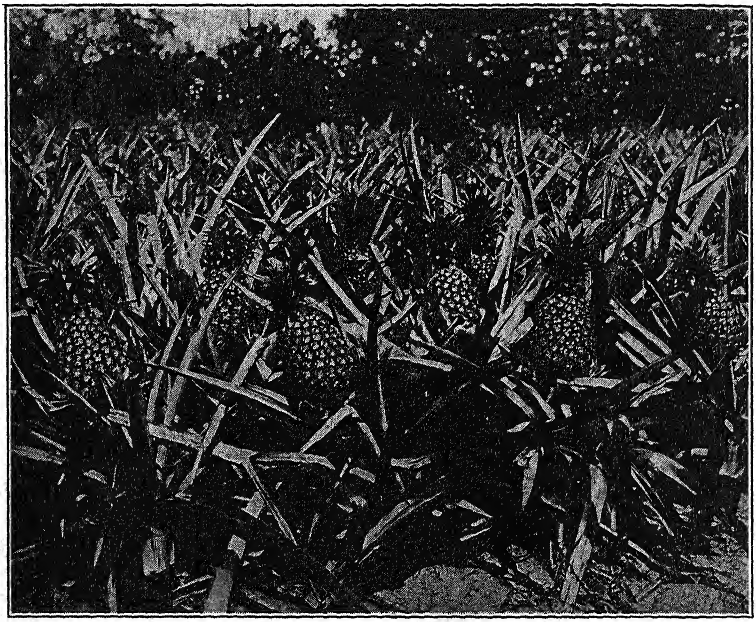

FIG. 205.—Pineapple, *Ananas sativus* (Bromeliaceae), growing in a Florida garden. (From Gager's General Botany.)

(peanut); palm family (coconut); myrtle family (Brazil nut); and cashew family (pistachio).

Vegetables. In a popular sense a " vegetable " may either be a vegetative structure of the plant, such as roots, stems, or leaves, or a reproductive structure, that is a true fruit, botanically. For example, the part of the lettuce plant used for food is the leaves, and of the potato plant, the tubers. In both these vegetables,

vegetative parts of the plant are used. On the other hand, the squash, commonly called a "vegetable," is in reality a true fruit, being derived from the flower, a reproductive structure.

The common families producing "vegetables" which are dug from the soil are as follows: potato family (Irish potato); morning-glory family (sweet potato); lily family (onion, garlic, leek, chive); goosefoot family (garden beet); carrot family (carrot, parsnip); mustard family (turnip, rutabaga); composite family (Jerusalem artichoke).

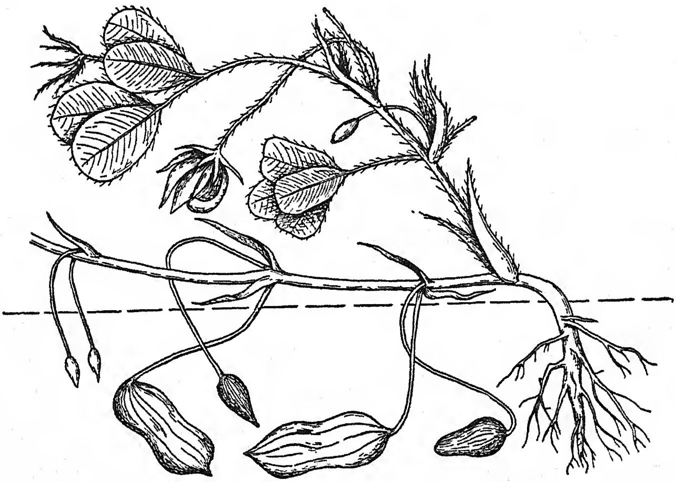

FIG. 206.—Peanut, *Arachis hypogaea*; entire plant, reduced. The flower stalks after pollination grow downward and the fruit is ripened underground. (After Jones, from Robbins, in Botany of Crop Plants.)

The leafy vegetables include those known as salad plants or pot herbs. Chief of these are: lily family (asparagus); mustard family (cabbage, kohlrabi, kale, borecole, Brussels sprouts, water-cress); goosefoot family (spinach); carrot family (celery, parsley); composite family (lettuce).

The so-called fruit vegetables include representatives of the following: cucurbit family (squash, pumpkin); potato family (tomato, eggplant).

QUESTIONS

1. Why are potatoes grown from the true seeds not true to type?
2. The Burbank variety of potato was developed from the true seed. How is the variety kept true to type?
3. What is the native home of the potato?
4. What is the principal food stored in the potato?
5. How do ordinary sweet potatoes differ from " yams "?
6. What gives the red color to the common garden beet?
7. Find out what you can about the manufacture of sugar from the Jerusalem artichoke.

Beverage plants. Each of the three ancient centers of agriculture has furnished to the world a valuable non-alcoholic beverage. **Tea** (*Thea sinensis*) is a native of the orient; **coffee** (*Coffea arabica*) came originally from the Mediterranean region; and the cacoa tree (*Theobroma cacao*), the source of **chocolate,** belongs to the American tropics. Commercial tea is the leaves of the plant, the coffee of commerce is the seeds, and commercial chocolate is also the seeds. What is the difference between " green tea " and " black tea "? What are the chief coffee-producing countries?

Sugar plants. The world's supply of sugar is derived chiefly from two plants, sugar cane, and sugar beet. Sugar cane (*Saccharum officinarum*) is a member of the grass family, and a native of the tropics. The sugar beet (*Beta vulgaris*) is a member of the goosefoot family, and is grown in temperate climates. The juice of sugar cane is derived from the stalks, that of the sugar beet from the roots. The sugar extracted from the juice of these two plants is identical chemically. It is sucrose or cane sugar ($C_{12}H_{22}O_{11}$). Do you think there is any difference between sugar from the beet and that from the cane in sweetening power, or in its behavior when used in making candy, ice-cream, canned fruit, jellies, and preserves?

The sap of the sugar maple tree also supplies a considerable amount of sucrose sugar. A species of palm (*Phoenix sylvestris*) has long been a source of sugar in India. What is the average sugar percentage of cane? Of sugar beet? What is the food value of sugar? What are the principal sugar-beet-producing countries? Where is cane grown chiefly?

Spices and flavoring substances. A great number of plants yield spices. **Cinnamon** is derived from a number of different Asiatic trees of the laurel family. **Black pepper** is derived from

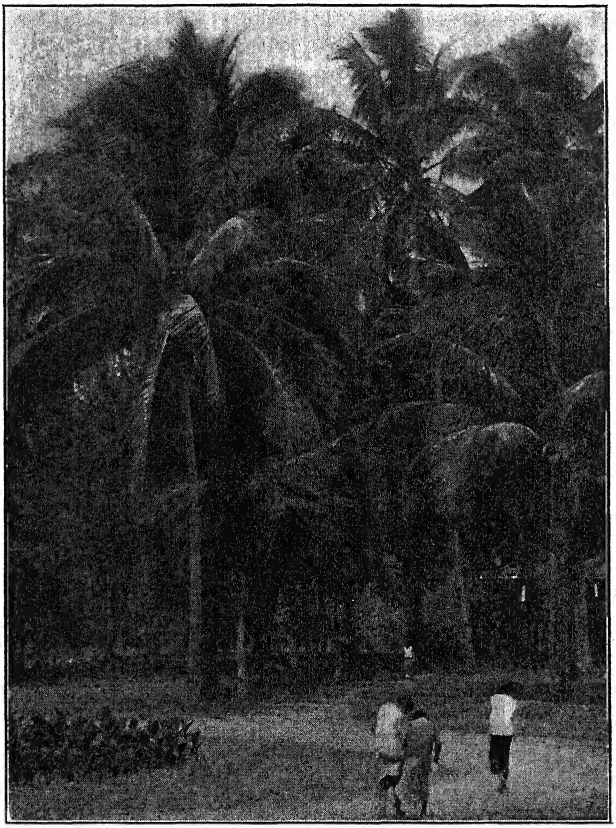

Fig. 207.—Coconut palm, *Cocos nucifera*, growing in central Siam. (Photograph by courtesy of Dr. Gordon Alexander. From Robbins and Ramaley, in Plants Useful to Man.)

the outer part of the unripe fruit of a woody vine (*Piper nigrum*), cultivated throughout the old world tropics. The inner stony part of the fruit of this same plant is the source of **white pepper.**

Cloves are a product of an evergreen tree, *Eugenia aromatica*, of the myrtle family. **Nutmeg** is the seed and **mace** the branched fibrous outer coat of the seed belonging to a tree, *Myristica fragrans*, which grows wild in the Molucca Islands and New Guinea. **Ginger** is the rhizome of a tall herbaceous canna-like plant, *Zinziber officinale*, a native of Asia south of the Himalayas. **Cayenne pepper** is derived from the tropical American plant,

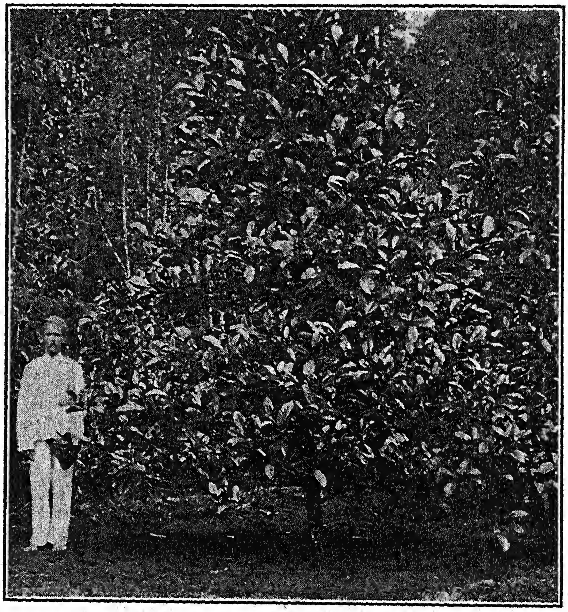

FIG. 208.—Coffee, *Coffea arabica* (Rubiaceae); young trees in the Dutch Government Agricultural Department plantation, Buitenzorg, Java. (From Robbins and Ramaley, in Plants Useful to Man.)

Capsicum. The principal flavoring substances are peppermint, wintergreen, lemon, and vanilla. **Peppermint** is extracted from the whole plant of a member (*Mentha*) of the mint family; **wintergreen** from the leaves of a heath-like plant (*Gaultheria*); **lemon** from the rind of the fruit; and **vanilla** from the vanilla bean, a tropical plant (*Vanilla planifolia*) belonging to the orchid family.

Food for livestock. The land animals employed by man as food and as beasts of burden are herbivorous, that is, they live directly upon plants. The plains, prairies, mountain lands, pampas, and other grass lands of the world support enormous numbers of livestock. Man has cultivated many plants for the

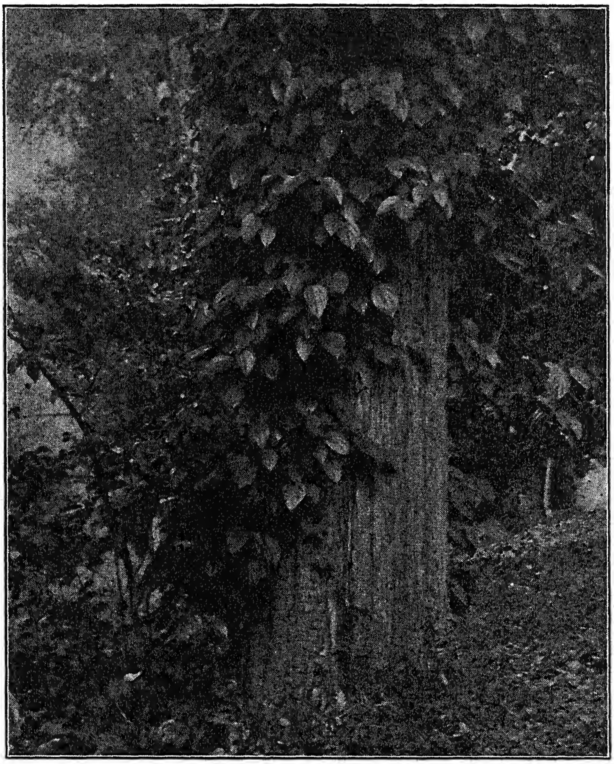

FIG. 209.—Pepper, *Piper nigrum* (Piperaceae); climbing upon a tree in a tropical garden. (From Robbins and Ramaley, in Plants Useful to Man.)

use of domesticated animals. Chief of these are the cereals, timothy, Sudan grass, and many other grasses, various clovers (*Trifolium*), alfalfas (*Medicago*), and certain root crops, such as mangel-wurzels, rutabagas, swede turnips, etc.

Problem 2. What are the principal industrial plants?

In addition to the common plants which yield food for man and beasts, we may consider also the following industrial plant products: (1) wood; (2) coal; (3) cork; (4) fibers, straws, and twigs; (5) resins and turpentine; (6) gums; (7) vegetable dyes; (8) fixed and volatile oils; and (9) rubber.

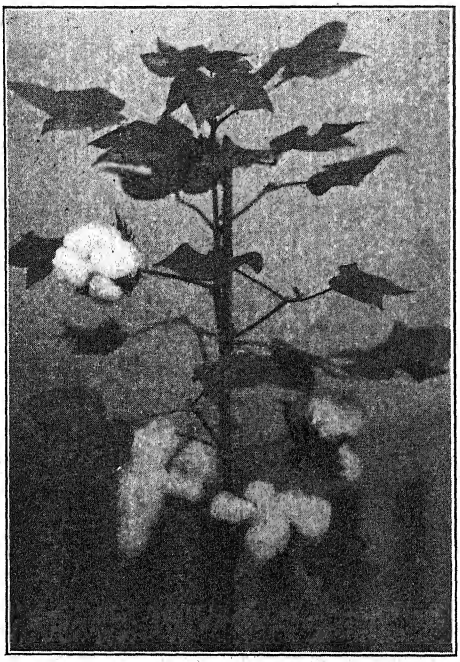

Fig. 210.—Upland cotton, a fiber plant of great economic importance.

Fiber plants. The most important fiber plants in the world are cotton (*Gossypium*), flax (*Linum*), hemp (*Cannabis*), sisal (*Agave* species). Fibers are used for a great variety of purposes: fabrics of all kinds, cordage, brushes, matting, paper, filling, plaiting, etc.

There are more than 40 species of *Gossypium*. The mature

fruit called the " boll " is filled with seeds, which are covered with hairs, the cotton fibers. The cotton fiber is thus classed as a " surface fiber." As a rule, there are two kinds of hairs on the seed: (*a*) the long hairs, the so-called lint or commercial fiber; and (*b*) short hairs or fuzz. The principal varieties of cotton are the Sea Island cottons, Egyptian cottons, and American Upland cottons. The finer threads are made from Sea Island cotton; ordinary threads and yarns are from Upland cotton. What is a cotton gin?

The flax plant (*Linum-usitatissimum*) is a slender annual plant which has been used for its fiber as far back as the Swiss dwellers of the stone age. The fiber of flax is in the bark. It is known as "bast fiber." From the fiber is made the linen of commerce. Our finest linens are from foreign-grown flax, the best known of which are the Flemish, which is grown in Belgium, and the Irish linen. Flax fiber is also employed for making thread, fishing lines, seine twines, canvas, and duck.

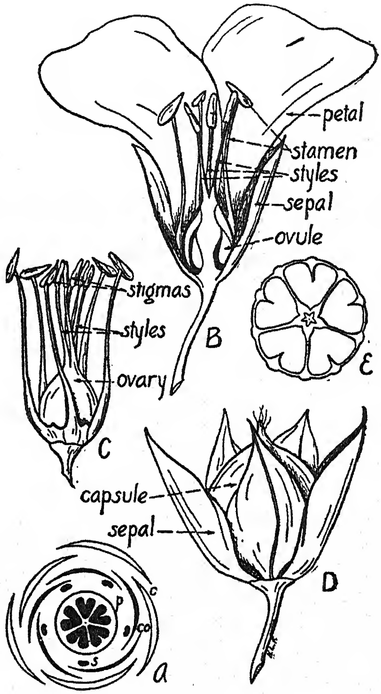

FIG. 211.—Flax. A, floral diagram—c, calyx; co, corolla; s, stamens; p, pistil. B, Median lengthwise section of flower. C, calyx and corolla removed. D, fruit, external view. E, cross-section of fruit. (From Robbins, in Botany of Crop Plants.)

Hemp (*Cannabis*) is a representative of the mulberry family. The stem yields a fiber which is the strongest and most durable of soft fibers with the single exception of flax. Like flax, hemp is a " bast fiber." Hemp fibers are used in the manufacture of sail cloth, yacht cordage, binder twine, sacking, bagging, rope, etc.

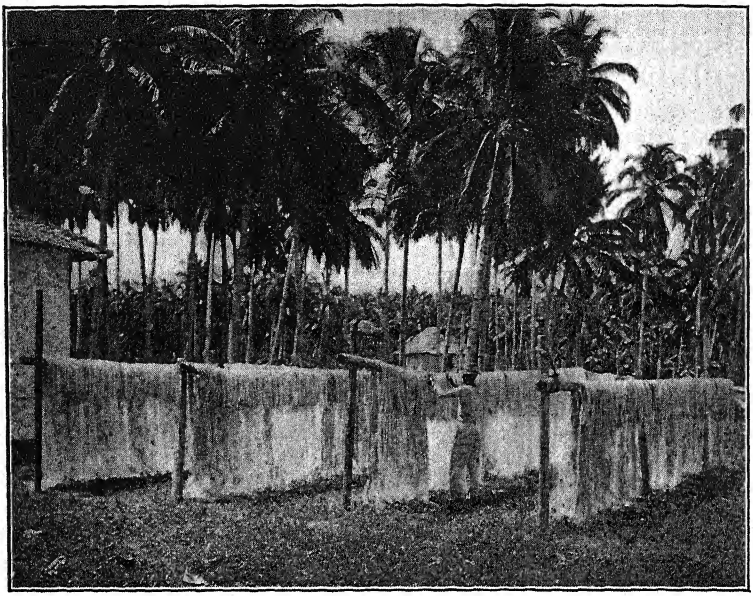

FIG. 212.—Hemp. Fiber hung up to dry. Coconut palm in background. (From Gager's General Botany.)

FIG. 213.—Manila fiber plants, *Musa textilis*, growing in an experimental garden at Buitenzorg, Java. (From Robbins and Ramaley, in Plants Useful to Man.)

The chief fiber competing with hemp is jute. Jute is produced in India from two species of plants (*Corchorus* species) of the linden family. It is used extensively for the manufacture of sugar sacks, gunny sacks, burlaps, grain sacks, and wool sacking.

The husk of the coconut, a tropical tree of the palm family, yields an inferior fiber which is employed in making coir rope and matting.

Manila fiber, sometimes called "Manila hemp," is derived from *Musa textilis*, of the Philippine Islands, a plant closely related to the common banana. The fiber, known as a "hard fiber," is obtained from the flower stalk and leaf bases. Older and coarser fiber is used for cordage (Manila rope and twine); the younger and softer material is used for fine fabrics.

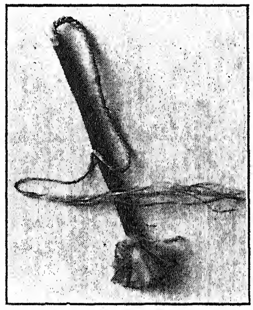

FIG. 214.—Whip made from bast fibers. The abundance, flexibility, and strength of the bast fibers of some stems is illustrated by the fact that a Filipino lad was able to make this whip using the fibers of the bark of a native Philippine shrub after the wood and parts of the bark were removed.

Sisal hemp is derived from species of *Agave*, growing in tropical and subtropical America. The so-called century plant of parks and gardens is *Agave americana*.

Exercise 140. Microscopic examination of fibers. Examine microscopically the following fibers, and learn to recognize the important differences: wool, silk, cotton, flax, hemp, and jute. After familiarizing yourself with the fiber characteristics, examine different kinds of cloth, identifying the kind of materials of which it is made.

Wood. The uses of *wood* are so well known that they need not be described in detail; it will be sufficient to mention a few of its uses as follows: fuel, building materials, furniture, vehicles, musical instruments, cooperage, boxes, watercraft, fences, poles, posts, and wood pulp for paper-making. What are the structural differences between "soft wood" and "hard wood?"

Coal. Botanically, coal is ancient vegetation variously modified through decay, pressure, and heat. What are the differences between soft coal and hard coal?

Cork. Cork is derived chiefly from the cork oak (*Quercus suber*), a tree of the Mediterranean region. What are the various uses of cork? Why is cork waterproof?

Resins. The resins of commerce are exudations of trees and shrubs, chiefly of the pine family. The best known resin is the

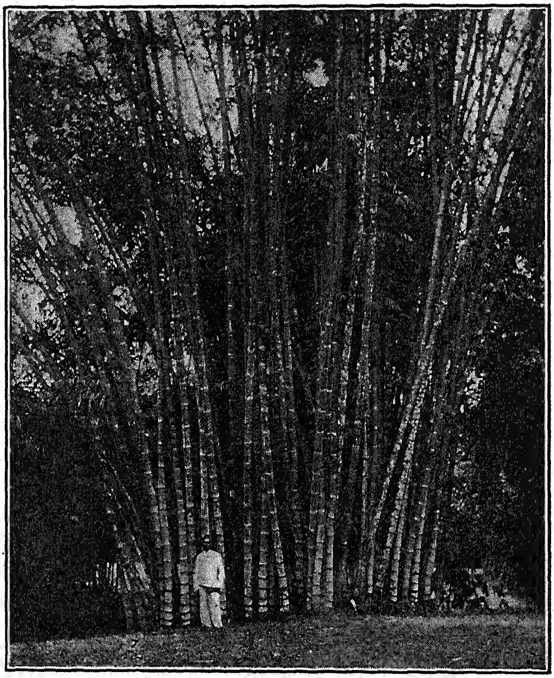

FIG. 215.—A large bamboo, *Bambusa polymorpha*. Peradeniya, Ceylon. (From Robbins and Ramaley, in Plants Useful to Man.)

common rosin derived from one or more species of pine in our southern states. Rosin has a number of applications; it is an ingredient of varnishes, low-grade sealing wax, and cheap soaps, and it is used in various electrical instruments.

Turpentine. Turpentine is a volatile substance obtained by distillation of the exudate of pines; it is the substance in which the resin proper was dissolved as it occurred in the tree. What are the chief uses of turpentine?

Vegetable gums. The vegetable gums are exudations from the stems of many trees and shrubs. **Gum arabic** is derived from a shrub, *Acacia senegal*. **Gum tragacanth** comes from *Astragalus gummifer* of southwestern Asia. **Dextrin** is produced artificially from starch. It is used in place of the more expensive natural gums to make mucilage. **Gamboge** is the dried juice from the bark of an evergreen tree, *Garcinia hanburyi*; it is made into a bright yellow paint and also has medicinal uses.

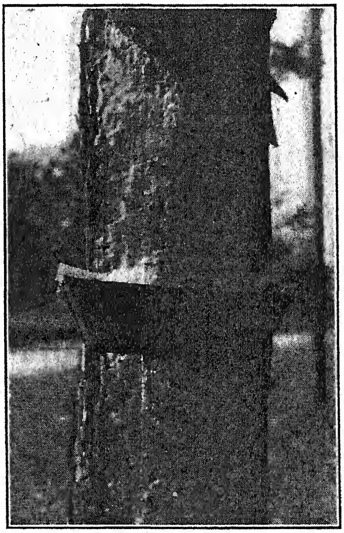

Fig. 216.—A pine tree in Alabama, tapped for collection of turpentine.

Plant dyes. Many plants have bright-colored juices in the roots or sometimes in other parts. One of the chief plant dyes is logwood, *Haematoxylin campechianum*, a Brazilian plant. From it is prepared haematoxylin, a stain used by microscopists. Indigo, from the leaves of certain shrubby plants of the pea family, is of little commercial importance today, having been replaced by synthetic coal-tar products.

Oils. There are two different kinds of vegetable oils: (*a*) fixed oils, which make a permanent stain or "spot"; and (*b*) volatile oils, which do not make a permanent stain or spot. The principal fixed oils, and their chief uses, are as follows: cottonseed oil (*Gossypium*), food; cacao butter (*Theobroma cacao*), pharmacy; coconut oil (*Cocos nucifera*), food, soap; olive oil (*Olea europoea*), food, soap; peanut oil (*Arachis hypogoea*), food, soap; ape oil (*Brassica napus*), lubricant, food; linseed oil (*Linum usitatissimum*), paint, varnish; castor oil (*Ricinus communis*) medicine, lubricant; maize oil (*Zea mays*), food, paint; palm oil (*Elaeis guineensis*), soap, lubricant. The most important volatile oils, which are employed for flavoring, as medicine, and for perfumery, are as follows: clove oil (*Eugenia aromatica*), cedar oil (*Sabina

virginiana), nutmeg oil (*Myristica fragrans*), anise oil (*Pumpinella anisum*), thyme oil (*Thymus vulgaris*), wintergreen oil (*Gaultheria procumbens*), peppermint oil (*Mentha piperita*), and lemon oil (*Citrus limonia*).

Rubber. Rubber is obtained from the milky juice of many kinds of trees and shrubs but at the present time the Para rubber tree, *Hevea brasiliensis*, furnishes most of the world's supply. Crude rubber is prepared from the thick plant juice which exudes

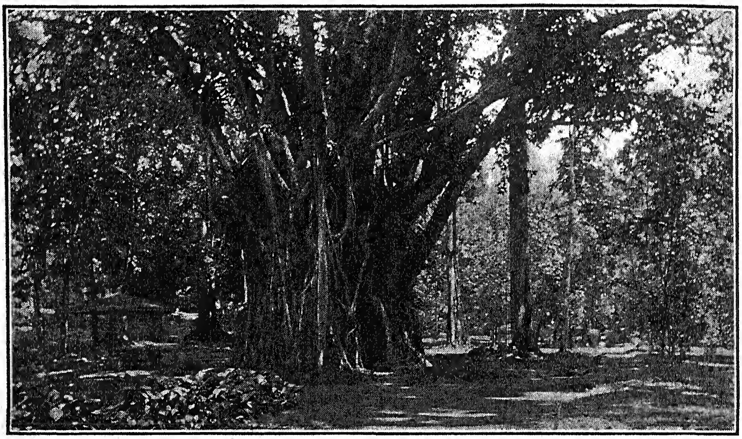

FIG. 217.—India rubber tree, *Ficus elastica* (Moraceae), in the botanic gardens at Buitenzorg, Java. (From Robbins and Ramaley, in Plants Useful to Man.)

from the bark after it is slashed. Somewhat like rubber is the substance gutta-percha derived from the milky juice of *Palaquium oblongifolia*, native of the East Indies and the Malay Peninsula. It is used chiefly to insulate and waterproof submarine and underground electric cables. A member of the composite family, known as "Guayula" (*Parthenium argentatum*), has been cultivated to some extent in the arid sections of the United States as a source of rubber.

Suggested activity. Find out what you can about the discovery of vulcanization, a process which revolutionized the rubber industry.

QUESTIONS

1. Describe the method of wood formation in a tree.
2. What is quarter-sawed wood?
3. What is responsible for the grain of wood?
4. Do you know wood that is heavier than water?
5. Describe the method of bark formation in a tree.
6. What is the chemical composition of cotton fibers?
7. What is the source of the mucilage used on postage stamps?
8. Has man been successful in making a synthetic rubber?
9. What is the chemical composition of the milky juice or latex from which rubber is made?

Problem 3. What are the principal medicinal plants?

The early history of botany is closely associated with the development of medicine. The botanists of primitive peoples were also the physicians, priests, and sorcerers. In the healing of disease some plants or plant parts are employed as charms, some as fetiches, some as true medicines used for supposed physiological effect. From the earliest time the Chinese have been active in the use of " herbs " for medicinal purposes. They have collected roots, berries, and barks, and made from them various extracts, decoctions, and infusions.

It is customary in modern medicine to judge of the value of drugs by their physiological action upon lower animals. The so-called " active principle " in a plant or plant part may be an alkaloid, a glucoside, a fixed or volatile oil, a resin, or some other specific chemical substance.

Examination of the Official United States Pharmacopoeia, which is an authoritative book containing the formulas and methods of preparation of medicines, etc., for the use of druggists, will reveal the fact that many hundreds of plants yield drugs.

However, there are now many more different kinds of drugs than are really necessary or desirable, for numerous drugs of plant origin have essentially the same physiological action. The most important drug plants in the world are as follows:

1. Poppy (*Papaver somniferum*). The dried juice, known as **opium,** from the capsule, is a great reliever of pain. Opium is obtained from the unripe fruits which are cut with a knife to allow

the milky juice to exude. This juice when dried forms the opium of commerce and contains about 10 per cent of the alkaloid **morphine.**

2. **Cinchona** (*Cinchona* spp.), a member of the madder family. This medium-sized evergreen tree yields a bark known as Peruvian bark, which furnishes **quinine,** a specific cure and preventive of malaria. Quinine is a white amorphous or crystalline powder, very bitter to the taste, which exists in cinchona bark to the amount of 5 to 10 per cent. It is one of the very few specific

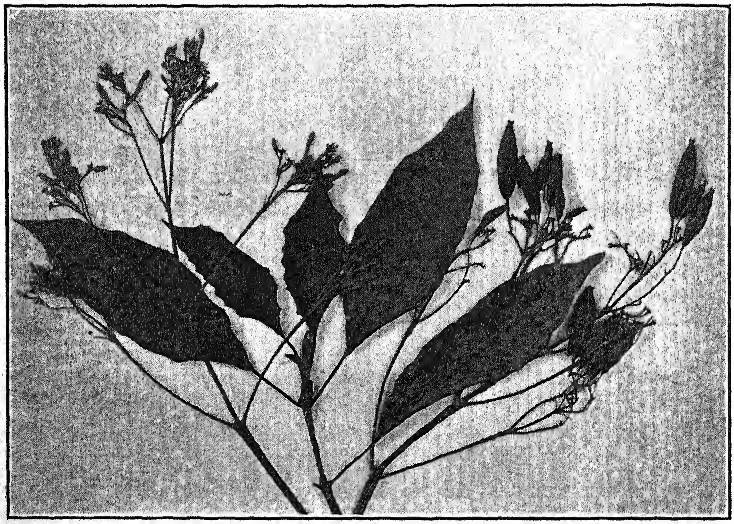

FIG. 218.—Cinchona in fruit, photographed from a herbarium specimen. (From Robbins and Ramaley, in Plants Useful to Man.)

medicines. Today the Dutch have made their Javanese plantations "the throne of the quinine trade." The Dutch are practically the only exporters of cinchona in the world. They have about 25,000 acres under plantation.

3. **Digitalis** (*Digitalis purpurea*). This plant is a member of the figwort family. The leaves contain various glucosides, chief of which is **digitalin,** a drug which slows up heart action, and hence is used in the treatment of certain cases of heart disease.

4. **Belladonna** (*Atropa belladonna*). This plant, a member of the nightshade family, to which also belong potato, tomato, tobacco, petunia, etc., yields a drug known as **atropine,** an alkaloid employed by oculists to paralyze those muscles of the eye which cause accommodation.

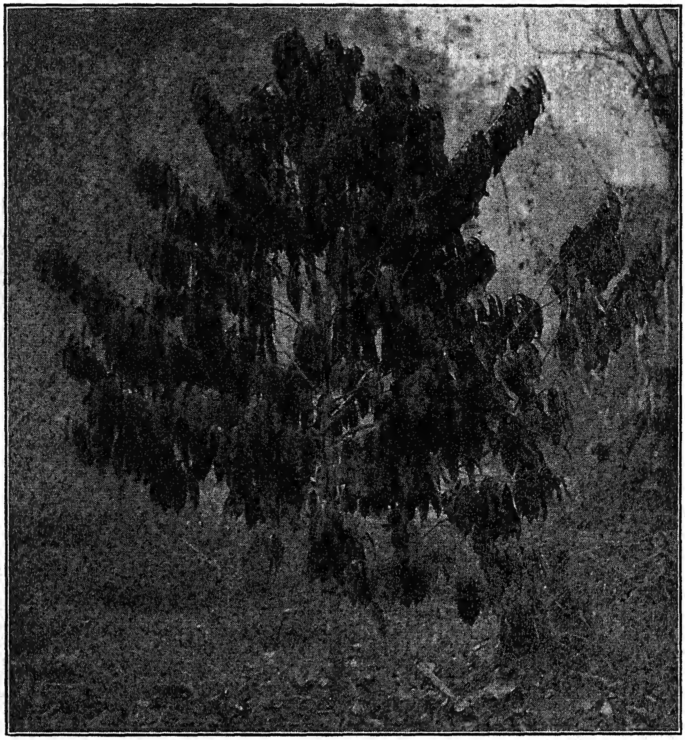

FIG. 219.—Chaulmoogra; young tree on the grounds of the leper hospital at Chiengmai, Siam. (Photograph by Dr. Gordon Alexander. From Robbins and Ramaley, in Plants Useful to Man.)

5. **Chaulmoogra tree** (*Taraktogenos kurzii*). This plant, also known as "Kalaw," is a tall jungle tree of north Burma, which yields **chaulmoogra oil,** employed in the treatment of leprosy.

Other plant drugs of importance are as follows: **gum arabic,** a mucilaginous substance which is an exudation from the trunk and

branches of the gum arabic tree (*Acacia senegal*); **castor-oil,** obtained from the seeds of the castor-oil plant (*Ricinus communis*); **calamus,** from the underground stem of sweet-flag (*Acorus calamus*); **camphor,** a gum-like drug obtained by distillation from the wood of the camphor tree (*Cinnamomum camphora*); **menthol,** from the volatile oil of peppermint; **strychnine,** an alkaloid derived from the seeds of the nux vomica tree (*Strychnos nux-vomica*).

Problem 4. What are the principal by-products derived from plants?

Innumerable by-products are derived from plants. The chief product of the cotton plant is the long fiber; but there are numerous important by-products. The short lint or fuzz, known as "linters," which is not removed in ginning, is taken from the seeds and made into poor-quality twine, carpets, and batting. Now, "linters," 85 per cent of which is cellulose, are the basis of numerous products: leather substitutes, toilet articles of all kinds, kodak and movie films, rayon, fine paper, and collodion. Cottonseed hulls are used in the manufacture of paper and fiber board from which are made gear wheels, trunks, etc.; and the hulls are also utilized as fuel and fertilizer, and as a cattle food. Cottonseed oil is one of the most valuable products of the cotton plant. The oil is in the embryo of the seed. This oil is now produced in very large quantities, this country having exported 33,673,000 gallons in 1921. It appears on the market as "table oil," "sweet nut oil," and "salad oil." Some of it is utilized in the manufacture of soap, also of "oleomargarine" and other butter and lard substitutes. Guncotton is an explosive made by treating cotton or some other form of cellulose with nitric or sulphuric acid. Those kinds of guncotton soluble in alcohol or ether are used in the manufacture of rayon, celluloid, etc.

The flax plant yields both fiber and oil (linseed oil). Neither can be regarded as a by-product. In the manufacture of linseed oil from the seed of flax, the residue from the crushed seeds gives a cake or meal which is a valued stock food. Flax seeds are used whole for various medical purposes. The threshed straw of the

northwestern seed flax is employed to some extent for upholstering, for insulating cold-storage plants, refrigerator cars, and ice boxes. The principal use of hemp (*Cannabis*) is as a fiber plant. The seeds are often fed to poultry and cage birds; the leaves and flowers yield a drug known as *Cannabis indica;* the seeds give an oil which is used for making soft soaps and as a paint oil, and low grades are utilized for certain varnishes; hemp stems make a fair grade of paper.

The sugar beet (*Beta vulgaris*) furnishes a large proportion of the world's sugar supply. The by-products of the industry have enormous value. The tops, molasses, and pulp are valued stock feed, and the waste water from the manufacturing process is boiled down, yielding fertilizer. It has been demonstrated that it is possible to manufacture fusel oil, alcohol, rum, and vinegar from the refuse beet molasses.

No other cereal is put to such a variety of uses as is corn. Some economical use has been found for nearly every part of the plant. It is a food for man and beast. Corn oil is obtained from the embryo; it is used for salads, in cooking, in the manufacture of soap and paints, and sometimes it is vulcanized into a cheap grade of rubber substitutes. The manufacture of corn starch consumes about 50,000,000 bushels of corn annually in the United States. Commercial " glucose " is a thick syrup derived by the partial hydrolysis of starch, and is employed as the basis of many manufactured jellies and preserved fruits. Artificial gums, known as dextrin and British gums, are made from corn starch; they are used on envelopes and postage stamps, and also in many of the textile industries. The pith from the stalks is made into explosives and also employed as a packing material. The stalks as a whole have served as a source of raw cellulosic material, from which numerous products can be made. Corn cobs are still in demand for pipes. A fine grade of charcoal is manufactured from corn cobs. Corn cobs also have a practical value for the production of furfural, paper stock, organic solvents, artificial silk, etc. Paper is made from the stalks, and packing for mattresses from the husks. Corn cake, left when oil is pressed from the embryos, is a stock food. And corn is the most economical source of starch for alcohol manufacture in the United States.

The sugar-cane plant also yields many valued by-products. The molasses is used for baking purposes and as a table syrup; poorer grades are made into rum and alcohol, and used as stock food. The refuse has value as a fertilizer. Sugar-cane bagasse was formerly used only as fuel, but now it is made into wall board.

The soy bean (*Soja max*) is the most important legume in Asiatic countries. The chief product of the bean is the oil which is expressed from the seeds, and the plant is grown principally for that purpose. The plant has a number of less important uses. For example, after the oil is expressed from the seed, the "cake," either unground or ground into a meal, is used as stock feed or as a fertilizer. The seeds of soy beans are sometimes used as a substitute for coffee.

Peanut seeds yield an oil, a nearly colorless product, employed as a salad oil, and to a limited extent in the manufacture of soap and oleomargarine. Peanut butter has become a standard food. Peanut meal, the product left after pressing the oil from the seeds, is a high-grade stock feed.

Almond seeds yield an oil used as an ingredient of flavoring extracts, and the seeds are a source of prussic acid.

Cider is the juice of apples. In the transformation of cider to vinegar, two fermentation processes take place; alcoholic fermentation, and acetic acid fermentation. The characteristic properties of vinegar are due to acetic acid.

The juice of quince is sometimes employed to flavor manufactured food products.

The buckwheat plant (*Fagopyrum vulgare*) is grown chiefly for the "grain" which is made into buckwheat flour. The "middlings" (hulls, mixed with bran) are employed as a bedding for stock; and, not to be disregarded, are the flowers which produce an excellent grade of honey.

Agave species are grown largely for their fiber (sisals), but the juice of the plant is fermented to give a drink, **pulque**.

In addition to its supply of fruit, the date palm furnishes material for building, for ropes, baskets, and numerous other articles.

Rice hulls are used as a stock food; rice straw as a food for

stock, and also in the manufacture of paper, straw hats, straw board, etc.

The orange gives an important by-product in the form of an oil, which is employed in the manufacture of perfumes, soaps, and flavoring extracts. Waste oranges may be used for this purpose. One of the chief by-products of the lemon industry is lemon oil, which ranks second to vanilla extract in the quantity consumed.

The potato plant is cultivated for its tubers, which are used chiefly as a food for man. But it is an important source of commercial starch and of alcohol.

In the canning of tomatoes large amounts of refuse accumulate. The oil expressed from the seeds is used as a soap oil, which may be made into a drying oil for paint; the meal is used as a stock food.

Carrot roots, grown mostly for a table vegetable, contain a yellow pigment, carotin, which is sometimes extracted and used for coloring butter.

The grape plant has a number of by-products. Brandy, feed, fertilizers, and acetic acid are made from the pomace. Tartaric acid is manufactured from the stems, shells, and the "lees" of wine. The seeds are used as a food for stock and as a source of tannin and grape oil.

Sweet potatoes are used chiefly as a human food. Flour, starch, glucose, and alcohol are minor products of the root.

Problem 5. How do plants interfere with man?

Not all plants are useful. Many are of economic importance because they interfere with man's farming operations, or they injure his health or that of domestic animals. The principal groups of harmful plants are as follows: (1) weeds, (2) fungi which cause animal and plant diseases, (3) plants directly poisonous to man and livestock, (4) hay-fever plants.

WEEDS

We have come to consider as "weeds" those plants which tend to grow where they are not desired; plants which tend to resist man's efforts to subdue them; plants which will grow in almost any kind of soil and under all conditions; plants which pro-

duce seeds in enormous numbers and have other rapid methods of propagation; plants which in themselves sometimes are truly beautiful, but which for us have lost their charm; plants useless and troublesome.

Losses caused by weeds. The losses caused by weeds fall into two chief classes: (1) losses brought about by a decrease in yield or quality of crop, (2) losses brought about by an increase in the labor cost of growing the crop.

Weeds rob cultivated plants of water. Weeds do great injury in using up moisture. It is said that a large weed will use a barrel of water during the season. The sunflower plant requires almost twice as much water as corn to produce the same amount of dry matter; the water requirement of ragweed is about three times that of millet. These figures show the injury that weeds do to our crops through their great demand upon soil moisture. In fact, the main benefit derived from cultivating corn and other crops is in the removal of weeds which compete with them for soil moisture.

Weeds crowd out and shade crop plants. By shading, weeds may retard in crop plants the process of food-making (photosynthesis). They may even prevent seedlings from getting a start. Moreover, certain fungus pests develop better in the shade than in direct light.

Weeds harbor insects and fungus pests. Insects and fungi often spread from weeds to neighboring cultivated plants. **Clean culture about roadsides, fence rows and ditch banks is strongly** recommended to prevent the spread of such pests. Insects deposit their eggs upon the weeds, and when the larvae hatch they migrate into the fields. Insects often go into hibernation somewhere near their native food plants, many of which are weeds, and from them they scatter to adjoining fields of cultivated plants. Insect pests gradually become more and more numerous until, native plants being insufficient for their food supply, they move to adjacent fields of cultivated plants. For example, the **beet webworm** prefers lamb's quarters, Russian thistle, and *Atriplex* rather than the sugar beet as plants upon which to deposit their eggs. Fields infested with or bordered by these weeds attract the webworm moths, and when these plants are exhausted by the

larvae, they move to nearby beets. **Grasshoppers** are always worse next to ditchbanks and roadsides, fence rows, and other waste land, overgrown with weeds and grass. Grasshoppers rarely lay their eggs in cultivated fields, but select the native haunts in preference. **Potato bugs** flourish on greenberries, nightshade, and buffalo bur. **False chinchbug,** which does great injury to seed crops, breeds and feeds during the early part of the season on shepherd's purse and other wild mustards.

It is now well established that the fungus causing stem rust of wheat is harbored by certain grasses such as wild barley and that it may spread from wild barley and other grasses to wheat. Certain wild mustards may serve as a host for the fungus causing " club-root " of cabbage.

Weeds retard the work of harvesting grain. Weeds increase the pull for the horses and cause an extra wear and tear on machinery. Dodder may so mat alfalfa plants together as to make harvesting extremely difficult. Weeds increase the labor of threshing, and make an added cost in cleaning the seed.

Weeds and dockage. One of the most serious losses occasioned by weeds in fields results from the **infestation of the grain or seed crop.** Farmers annually haul thousands of tons of weed seeds, chaff, and other inert matter to the mill in their wheat. And, of course, they are docked for this unclean wheat, and rightly so. Moreover, unclean seed means that the fields which produced the seed were weedy. And, what is worse, it means that the next crop grown from such seed will be weedy.

Some weeds injure stock. The beards of downy brome grass, wild barley, and certain other grasses may work into the gums of animals, causing ulcers and the loss of teeth. Some weeds, such as cocklebur and sandbur, injure wool and disfigure the tails and manes of horses. A number of weeds are poisonous to stock. Not only do weeds decrease the crop yield, but when they are eaten they may also cause the death of stock.

Weeds retard the drying of grain and hay. Many weeds are succulent and hold moisture, thus retarding the drying of crop plants with which they are mixed.

Some weed seeds, such as cockle, damage the quality of dairy products. Weeds such as common ragweed, wild onion,

and wild garlic, when eaten by cows, impart disagreeable flavors to milk, butter, and cheese.

Why weeds are successful plants. Seed production of weeds. Many weeds produce an enormous number of seeds. A large purslane plant will produce as many as 1,250,000 seeds; a single Russian thistle plant will ripen 100,000 to 200,000 seeds; tumbling mustard as many as 1,500,000 seeds.

The seeds of many weeds are very small and escape notice. A pound of clover dodder has 1,841,360 seeds; common plantain, 1,841,360 seeds; lamb's quarters, 604,786 seeds; Russian thistle, 266,817 seeds; wild mustard, 215,995 seeds; wild oats, 25,943 seeds. If 60 pounds of wheat are planted to the acre, and this wheat has 2 per cent of wild mustard seed, there will be distributed over that acre 388,791 mustard seeds, or 9 seeds in every square foot.

Vital weed seeds at different depths in the soil. Not only do weeds produce seeds in tremendous numbers, but also many weeds produce seeds with an **ability to live a long time.** The seeds of some weeds, when buried in the soil, may retain their power of germination for 15 to 30 years. This is true of the seeds of tall pigweed, black mustard, shepherd's purse, dock, yellow foxtail, chickweed, and others.

Some weeds seeds exhibit dormancy. Not all the seeds of a given crop of seed may germinate the first year; some may remain alive in the ground for a time. This has been given popular expression in the following statement: "One year of seed gives seven years of weeds."

Weeds as a class are hardy. Weeds as a class are resistant to insect and fungus pests. They also have the ability to withstand shading, excessive drought, temperature extremes, and other unfavorable conditions. Of all weedy plants, the worst are those with underground stems or rootstocks, which live over from year to year in the soil, and enable the plant to spread rapidly in all directions underground. These underground stems store food, and, although the plant is cut off above ground, new stems are sent up directly from below. **Weeds with rootstocks are particularly difficult to eradicate.** Well-known examples of such weeds are quack grass, poverty weed, and Canada thistle.

Weeds spread rapidly. It has been the history of nearly all agricultural communities that weeds increase in abundance and variety, unless concerted action is taken to combat them. Almost every year sees the first appearance of some weed in a community, and usually in a few years it is prevalent. In a few decades the Russian thistle has spread throughout the agricultural sections of the West, and in some localities is now a menace. In fact, some sections are being abandoned on account of the Russian thistle. Russian thistle seeds are now a common impurity of crop seeds. The entire plant may break off at the ground line, become a "tumble weed," and be blown for miles across the open country, distributing its seeds as it tumbles along.

Weeds have excellent means of seed dispersal. Some seeds, like those of the thistle, milkweed, sow-thistle, wild lettuce, and dandelion, have cottony or feather-like attachments which enable them to take long aerial journeys. Most seeds will float on water and, consequently, are carried by streams and irrigation waters. A number of seeds are provided with hooked prickles or barbs by which they attach themselves to the clothing of man or the hair of animals, and are thus carried from place to place.

Impure commercial seeds. Probably no other means of introducing weeds is so effective as the sale and distribution of impure commercial seeds.

Seeds are carried in screenings, baled hay, the packing about trees, and in feedstuffs. Some seeds are uninjured in passing through the digestive tracts of animals and consequently are spread on the field in manure. The use of feeding stuffs containing live seeds may result in the spread of noxious weeds. A threshing machine may carry weed seed from farm to farm. Some weeds are dragged by plows, cultivators, and harrows from one part of the field to another and even to adjacent farms. This is true of those perennial weeds with underground stems which are cut up into pieces by cultivating implements.

Wind and water are important agents in weed dissemination. Wind carries seeds, and in some instances whole plants, long distances. In the irrgated sections, **water is one of the chief means of spreading seeds.** Ditch banks are densely overgrown with weeds, which shed their seeds in the water; the seeds are carried

down stream, given a good soaking in transit, and planted on a well-soaked soil—all conditions being ideal for germination.

Birds may be responsible for the distribution of weed seeds. However, birds probably do more good in eating weed seeds than harm in distributing them.

Underground spreading of weeds. Perennial weeds, such as Canada thistle, travel considerable distances each year underground. A small patch in one corner of a field may appear harmless enough, but it may soon spread over a whole field by means of underground growth alone.

Classes of weeds. Weeds fall into three classes according to their length of life. It is necessary to know to which class a weed belongs before one can wisely proceed to eradicate it. These weed classes are:

1. Annuals. Those that live one year, such as Russian thistle, pigweed, wild oats, shepherd's purse, pepper-grass, foxtail, and ragweed.

2. Biennials. Those that live two years, producing seed at the end of the second year, such as wild carrot, wild parsnip, mullein, and bull-thistle.

3. Perennials. Those that live from year to year by means of underground parts. They are our worst weeds, and when once established are difficult to eradicate. Some common perennial weeds are wild morning-glory, or bindweed, poverty weed, Bermuda grass, dandelion, sow-thistle, and Canada thistle.

Annual and biennial weeds. Annual and biennial weeds produce seed but once and then die down entirely, root and all. They propagate themselves by seed alone. Consequently, all methods of controlling weeds of these two classes have for their object the prevention of seeding. Clearly, if they are kept from seeding, and pains are taken to prevent seeds from being introduced to the land in the many ways that are possible, annuals and biennials are kept in check on the farm.

Annuals and biennials are easily killed by cultivation. The seeds of some weeds of these classes retain their vitality in the soil for several years, consequently several years of cultivation may be necessary. The principle of eradication of annuals and biennials

is to prevent seeding, and to cause the seeds that are shed to germinate and then destroy the seedlings before they mature.

There are two kinds of annuals: **summer annuals** and **winter annuals.** Summer annuals germinate their seeds in the spring, produce a crop of seed in the late summer or fall, and die down. The seedlings are not capable of living through the winter season. Russian thistle, foxtail grass, frenchweed or fanweed, barnyard

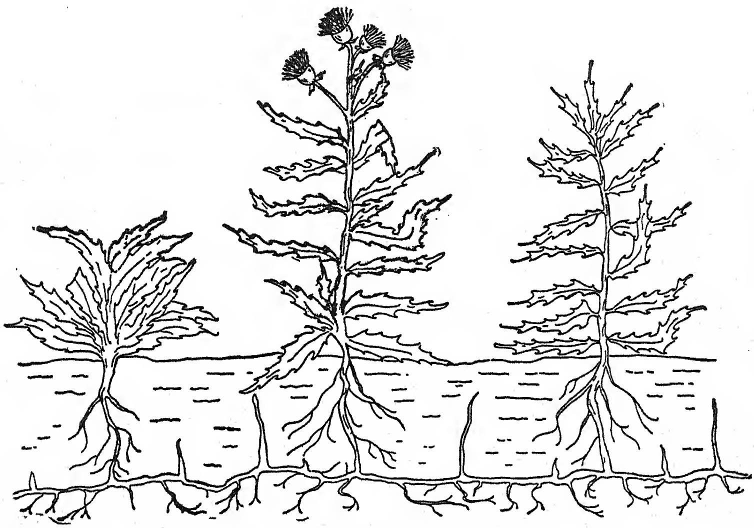

FIG. 220.—Canada thistle, a perennial weed that propagates both by seeds and underground stems. The illustration shows three different ages of shoots that have arisen from the underground stem and reached the surface, and several others which have not yet reached the surface.

grass, witch-grass, pigweed, and lamb's quarters are common summer annuals. Winter annuals come up from seed in the fall and live over the winter in the seedling stage, producing flowers and fruit the following spring or early summer. Shepherd's purse, pepper-grass, and prickly lettuce belong to this class. The seeds of winter annuals germinate after fall rains, and the young seedlings are easily killed at this time by cultivation. Winter annuals frequent stubble fields.

Perennial weeds. As has been stated, perennial weeds live from year to year without renewal from seed. They propagate themselves by means of both seed and vegetative growth (roots and underground stems). It is not sufficient to prevent seeding alone, although this should be done. All methods of holding in check or eradicating perennial weeds have for their object the starving or smothering of the underground growth. It is well known that, if the top growth of a perennial weed is cut off, new shoots are sent up from the stems or roots beneath ground. This means, then, that the underground parts possess reserve food material which is called upon to produce new shoots. As soon as leaves are produced on the new shoots, the manufacture of food is begun by them, and some of this food, made in leaves, finds its way back into the roots or rootstocks which thereby gain in strength. A rootstock or perennial root will increase in size each year just as does a perennial stem above the ground; and the larger it gets, the more difficult it is to starve out. Old, well-established perennial weeds are very difficult to eradicate, for the reason that they have a large store of reserve food to draw upon in the production of one crop of leafy shoots after another. It is a common experience that one may, by a thorough cultivation, kill all the top growth of a perennial weed, and find that the plant soon comes up thicker than before. A second thorough cultivation may be followed by like results. Each time that top growth was removed and new shoots sent forth, reserve food in the roots and rootstocks was used up. What is needed in the eradication of a well-established perennial weed is persistence and patience, cultivation frequent enough to keep down all leafy shoots, and no stopping until the object is attained. This may mean a season or two of bare fallow, followed by a crop which will permit of clean cultivation. Some farmers place in a cultivated crop like corn, potatoes, beets, or beans but do not cultivate often enough or thoroughly enough to prevent perennial weeds from making headway.

Small patches of perennial weeds can be eradicated by spading up the soil, raking out and burning the underground parts, and hoeing off every sprout as soon as it appears, during at least two seasons.

Methods of weed control. Use of clean seed. The first principle in weed control is the use of clean seed. A lot of "clean seed" is one which contains only the larger and plumper seeds of the crop desired, and is free from sticks, stones, gravel, dirt, chaff, weed seeds, the seeds of other crops, smut balls, and small, shrunken seeds of the crop desired.

Preventing weeds from seeding. The second principle in weed control is the prevention of seeding. This means the use of a hoed crop or meadow crop. Weeds in small grain cannot be prevented from seeding; as a result, continuous cropping to grain leads to foul fields. It is the inevitable result of a one-crop system.

Cutting the weeds along roadsides and fences. Throughout our entire country, cultivated fields are surrounded or bordered by areas infested with weeds. Roadsides are the chief sources of weed-seed supply. It is true that states, counties, and cities have laws which require the mowing of weeds along roadways prior to their seeding. But in very few instances is the regulation adequately enforced. As a matter of fact, weeds come to maturity and stand man-high along our roadsides, contaminating the adjacent cultivated fields and gardens.

Giving special attention to manure and screenings. The seeds of many weeds are not injured by passage through the digestive tract of an animal. Consequently, weedy hay, weedy bedding, grain-carrying weed seeds, or unground screening are a source of contamination. Many stock foods contain unground screenings in which may be found many small weed seeds, such as the plantain. Cases are known in which the weed seeds from this source, wild oats, for example, have been carried to the field in the manure. Well-composted manure contains no visible seeds. All screenings containing weed seeds should be thoroughly ground or steamed before they are fed. It should be added here that weed seeds are destroyed by the fermentation processes which ensilage undergoes.

Use of cultivated or cleaning crops. Crops such as beets, potatoes, beans, and corn which permit frequent cultivation are rightly called cleaning crops. Practically all annual and biennial weeds readily succumb to cultivation, and perennials are effectively held in check. Continuous cropping, particlarly to small grain,

which does not allow cultivation, inevitably leads to weedy fields. Cultivated crops are a necessity in any scheme to eradicate weeds.

Rotation of crops. "Crop rotation" is practically a synonym of "good farming." In fact, the control of weeds is one of the principal reasons for crop rotating. There are farms on which weeds are of little consideration, either in increasing the labor expended or in decreasing crop yields. And these farms are ones on which a definite plan of crop rotation is systematically adhered to. One cannot expect to follow a continuous system of cropping without trouble with weeds. Even old stands of alfalfa frequently become weedy, and must be plowed up and placed in a cultivated or cleaning crop.

Exercise 141. Field trip. Visit a weed-infested vacant lot or field. Find out by asking other people, or by the use of weed manuals, the common names of the different weeds which you do not already know. Is the habitat mesophytic, xerophytic, or hydrophytic? What weeds seem to be best fitted to the surroundings? Which of the weed characters mentioned in the text are possessed by the most successful of these plants? What plants of the habitat seem to be losing in the struggle for possession? Name qualities from the list in the text which the losing plants seem to lack.

Exercise 142. Field trip. If you can find a weed-infested garden or field, compare the condition of the crop plants which are struggling against the effects of the weeds with the condition of crop plants in a well-kept garden or field. List the reasons for the difference in the condition of the crops in the two situations. When left to themselves, why do weeds win over crop plants in competition for possession?

Exercise 143. Weeds which propagate vegetatively. Make a list of weeds which reproduce readily by vegetative means, and classify on the basis of the part of the plant which is important in vegetative reproduction, as quack grass, by rhizomes; purslane, by fragments of the stem.

Suggested activity. Make a collection of fruits and seeds of weeds, classifying on the basis of means of dispersal, that is, by propulsion, by wind, and by animals.

Exercise 144. Laboratory. Make a study of at least ten common weeds and record your data either in a table or as follows:

1. *Common name*...

2. *Habitat*:

   a. Where found growing.................................
   b. Mesophyte..........xerophyte..........hydrophyte.........

3. *Habit:*
   a. Mesophyte..........xerophyte..........hydrophyte.........
   b. Stem: height..........erect..........branching............ climbing..........prostrate..........rhizome............... succulent..........woody..........
   c. Leaves: large..........small..........medium............. simple..........compound..........succulent............... rosette..........mosaic..........
   d. Roots: primary..........lateral.........fibrous............. deep..........surface..........fleshy..........

4. *Reproduction:*
   a. Pollination: by wind..............by insects............by gravity..............
   b. Number and size of seeds.................................
   c. Methods of fruit and seed dispersal........................
   d. Vegetative reproduction...................................

5. *Length of life:* annual..........biennial..........perennial.........
6. *Protection against animals:* inedible..........spines.........offensive odor..........
7. *Native or introduced*..
8. *Means of control*...

PLANT DISEASES

One may express surprise that plants, as well as animals, become diseased, that they get "sick," and that they may need care and treatment to prevent them from succumbing to various maladies. But such is the case. The "plant doctor," or rather the plant pathologist, studies the characteristic symptoms of plant diseases, he determines the causes and searches for preventive measures and remedies. The science of plant pathology has made very rapid strides in recent years, and the plant pathologist is a very necessary person in our agricultural development. Scores of trained plant pathologists are now connected with the United States Department of Agriculture and with the various agricultural experiment stations and colleges.

It is estimated that the annual loss in the United States from potato blight amounts to $36,000,000; from wheat bunt, $11,000,000; and from oat smut, $6,500,000. Cereal rust caused a loss of about 200,000,000 bushels of wheat alone in the United States in 1916.

The causes of plant diseases. The different plant diseases may be classified as follows, according to their causes:

1. Those caused by the activity of living organisms.
    a. Caused by animals, such as worms and insects.
    b. Caused by plants.
        1. Parasitic bacteria, and other fungi, and slime molds.
        2. Parasitic seed plants.

2. Those due to adverse non-living environmental factors such as the chemical and physical condition of the soil, light, heat, precipitation, wind, lightning, smoke, soot, gases and smelter fumes, which may result in nutritive disturbances in the plant.

Diseases due to attacks of bacteria. Some of the chief bacterial diseases of cultivated plants are bacterial blight of alfalfa, blight of apple and pear, bacteriosis of bean, crown gall of a number of different plants, black rot of cabbage, and wilt of cucurbits. Bacterial diseases are often very destructive and spread rapidly. The bacteria gain entrance to the plant through wounds or through the pores (stomata) in the leaves. In the tissues of the host the bacteria find a suitable food supply, and there grow and reproduce rapidly. Bacteria are dependent organisms and draw their food from the host, causing in it nutritional disturbances and structural modifications which have characteristic symptoms.

Diseases caused by parasitic fungi. The large majority of plant diseases caused by plants are due to the activity of parasitic fungi. Well-known diseases brought on by these organisms are the mildews, the spots, rots, scabs, wilts, smuts, rusts, and cankers.

Diseases caused by parasitic seed plants. There is one very harmful seed plant which lives a parasitic life on a number of different plants, but is most harmful to alfalfa and clovers. This plant is dodder or love-vine. Dodder plants have slender, thread-like stems of a yellowish or orange color which twine and coil about the alfalfa plants. The dodder seeds germinate in the soil about the same time as alfalfa seeds. Later, the plants lose all connection with the soil. As the alfalfa plants grow, dodder keeps pace, spreading and branching extensively. Soon the dodder in a field may be detected by the dense growth of

yellow, tangled stems, or by the presence of patches of stunted alfalfa plants, and in severe cases, by a mat of dodder and alfalfa. The dodder plant sends small absorbing organs into the tissue of the host, and takes foods from it.

Diseases due to adverse environmental conditions. It is well known that hail will injure plants. Too much "alkali" in the soil may also cause serious injury to plants. Plants vary considerably in their ability to withstand alkali. The sugar beet, for example, can withstand much more alkali than corn or wheat or potatoes. Blueberries flourish in an acid soil, but become sick and die under other conditions. In certain parts of the irrigated sections of the West, nitrates have accumulated in the soil in such large quantities as to injure the vegetation and make it impossible to grow crops profitably upon them. This injury to plants is called "niter" injury. The accumulation of niter in the soil gives it a chocolate-brown color, and the accumulation is the result of soil conditions which favor the very great activity of certain nitrogen-fixing bacteria.

Too much water or too little water in the soil will cause the plants to be sickly and to be seriously reduced in their growth. "Tip burn" of lettuce is thought to be due to a fluctuation in the temperature and moisture supply, particularly in the presence of readily available potassium and nitrogen. Intense light may cause sunscorch, "bronzing," or sunscald. On the other hand, dense shade may cause plants to become weakly; for example, lawn grass in deep shade may languish and die. The injury of potato and cotton plants by lightning has been reported. In the neighborhood of cities where much smoke and fumes from manufacturing establishments are present, plants are injured; sulphur dioxide and other gases act as toxins. It is known that shade trees are harmed by small quantities of illuminating gases which may escape into the soil from leaking pipes.

Some plant diseases which can not be ascribed to any of the above causes are usually considered to be due to disturbances in plant nutrition. The causes of such diseases are often hard to determine. Any marked deficiency in one or more of the chemical elements essential to growth will result in an unhealthy development of the plant. The "pale" color of plants, a disease known

as **chlorosis**, may be due to a deficiency or unavailability of either magnesium or iron, both of which are essential to the formation of chlorophyll. "Die-back" of lemons has been ascribed to the poor nitrifying power of the soil.

Diseases caused by insects. So many of our crop plants are infected with insects that we are almost forced to the conclusion that there is not one without its insect enemy. In dealing with insect pests, two main types are recognized: that which includes insects with biting mouth-parts which feed on plant tissues, and that which includes insects with piercing and sucking mouth-parts which pierce the plant tissues and suck the plant juices. These small animals live upon the juices of the plant and reduce its vitality by destroying plant structures, or they feed upon the plant tissues, or steal the nourishment which is needed to make the plant grow well. Some of the principal insect enemies of crops are grasshoppers, cutworms, chinch bugs, alfalfa weevil, plant lice, webworms, woolly aphis, codling moth, scales, mites, borers, and leaf rollers.

The principles of disease control. In the preceding pages we have discussed the various causes of diseases in plants. Let us briefly outline the principles of disease control.

Determination of the cause. Of course, the first step in the control of a particular disease is to determine its exact cause. This may be difficult, at times, but a line of successful action can not be followed unless the cause is first ascertained.

Knowledge of the life history. If the diseased condition is due to an organism, it is essential to know the life history of this organism, so that it can be attacked at its most vulnerable period. For example, in those smuts, such as bunt of wheat, which infect the host only in the seedling stage, a knowledge of the mode of infection has led to a method of control which involves the destruction of spores on the seed and in the soil about the seed. Again, a knowledge of the life history of black stem rust of wheat has led to the eradication of the common barberry.

Cultural methods. It is becoming well recognized that many plants succumb to diseases because of a weakened condition brought about by poor cultural practices. A poorly nourished and weak plant, like a poorly nourished and weak animal, is often

more subject to the attacks of fungi than are strong vigorous plants. Hence, plants that are well cared for, that have ample water and mineral nutrients, and favorable soil, light, and temperature conditions, such that growth is uninterrupted, have greater powers of throwing off diseases than plants which suffer from a lack of these factors. However, very vigorous plants may be attacked by diseases.

Crop rotation. Our different crop plants have fungus diseases peculiar to them. For example, corn smut is known only on one common host, and that is maize. The smut spores survive in the soil and may infect the succeeding crop. By growing corn continuously on a given area, spores accumulate and increase the chance for infection. However, if the area is planted to a crop other than corn, the spores lose their vitality or germinate after a time. Then corn may be planted again in the area without fear of infection from the soil.

Consider another example, potato scab. It has been demonstrated experimentally that the fungus may persist in the soil for several years. Continuous cropping to potatoes only increases the soil infestation. But, if a crop not subject to the attacks of that particular organism is grown on the infested soil, potatoes may be grown there again after several years.

Disease-free seed. Great emphasis in the control of potato disease has been placed upon the necessity of using disease-free tubers ("seed"). Scab, *Rhizoctonia*, mosaic, dry rot, late blight, and other potato diseases may be carried into the soil by the tubers. Corn may carry within the kernel one or more disease-forming fungi. A number of the smuts are seed-borne. Anthracnose of beans is carried over from crop to crop largely in the seeds. Two general methods are adopted to secure disease-free seed, as follows: (1) seed selection, and (2) seed treatment.

Disease resistance. Much progress in the control of plant diseases has been made through the breeding of disease-resistant strains. In fact, this is one of the most hopeful lines of attack in combating plant diseases. Resistance may be due to a structure which prevents entrance of the organism, or to a nutritional condition that does not supply the proper kind of food, or to other causes not well understood.

No two plants are alike. They show variation. They may vary not only in such particulars as height, color, leaf shape, character of fruit, etc., but also in resistance to disease, or performance in some other direction.

The wilt disease of cotton at one time threatened the cotton industry in the southern states. Progress in its control has been due to the development of resistant varieties. Tests have shown that some varieties of cotton are several hundred times more resistant to the disease than others. Kanred wheat is a variety relatively resistant to black stem rust. Kieffer and McIntosh pears are relatively more resistant to bacterial blight (fire blight) than the Bartlett variety. Early Crawford and Elberta peaches are more resistant to brown rot of stone fruits than are such varieties as Triumph and Alexandra.

Sanitation. This includes destruction or removal of diseased tissues, the burning of refuse, and soil treatment.

Practical control of apple and pear blight, a bacterial disease, is brought about by pruning out infected twigs and smaller branches, and by scraping off all diseased tissue of the large branches and main trunk. The instruments employed are also sterilized.

In the case of black knot of plums and cherries, the developing knots should be pruned out as soon as they appear in the spring, and thus prevent the spread of spores which would develop on these swollen areas. Several prunings a season may be necessary to remove the diseased tissue.

The large, swollen, smut masses that develop on corn are well known as the source of clouds of spores which are readily blown by the wind and may infect other plants. Stalks affected with smut should be cut out and burned before the spores mature.

Crop residues and refuse often carry a disease from one season to the next. For example, if smutted corn is thrown on the manure heap, the spores may be carried to the field and become a source of infection.

As a measure of control in onion mildew, the tops of diseased plants should be destroyed. If they are left on the land or returned to it in the manure, infestation of the new crop will occur.

The mummied fruits characteristic of the brown rot of stone

fruits should be knocked from the trees, and together with those on the ground raked together and burned. These mummied fruits are the principal source of infection the following year.

Many other plant diseases are effectually controlled or held in check by the destruction of crop residue or refuse.

A number of disease-forming organisms live over in soil, either in the vegetative stage or spore stage. For example, damping-off fungi, which are often prevalent in potting beds, in greenhouses, in seedling nurseries, and sometimes even in fields, live from year to year in the soil, attacking the plants in the seedling stage. Fungi in the soil may be destroyed by steam sterilization of the soil and by drenching it with formalin. Club root of cabbage, a disease which attacks a number of cruciferous plants such as cauliflower, turnip, rutabaga, Brussels sprouts, radish, and other mustards, may be prevented or checked by applying lime to the soil, at the rate of about 100 bushels per acre.

FIG. 221.—Distributing sulphur by means of the aeroplane, in the control of fungous diseases. The aeroplane is now used to distribute various insecticides and fungicides. (From California Agricultural Experiment Station Bulletin 511.)

Application of fungicides. The spraying or dusting of plants with chemicals is now a common method of controlling many fungus diseases. Twenty-five years ago, however, the practice was little used. In the use of most fungicides the object is to cover the surface of the plant with a chemical which will prevent the germination and growth of spores that may already be on the surface or light on it later. The spore itself may absorb sufficient of the poison on the plant surface to kill it; or when the spore germinates, and sends out a slender tube, if there is a poisonous chemical in its path, and this is absorbed, growth is prevented. Thus sprays and dusts are preventives rather than cures.

Of course, the fungicide employed must not be injurious to the host. Fortunately, the thick cuticle which covers the surfaces

of twigs, leaves, and fruits usually prevents the absorption of sufficient poison to injure the host, providing the fungicide is properly made.

The common fungicides in use today are Bordeaux mixture, copper sulphate, ammoniacal copper carbonate, lime sulphur, flowers of sulphur, corrosive sublimate, and formalin.

Application of insecticides. Insect pests with biting mouthparts, as cabbage caterpillars, may usually be destroyed by spraying or dusting on a so-called stomach poison which is eaten by the insect as it feeds on the tissues of the plant. Insects with piercing mouthparts, as plant lice and scale bugs, are not affected by ordinary poisons placed on the surface of plants. These pests are destroyed by spraying with contact poisons. Examples of stomach poisons are Paris green and lead arsenate; examples of contact poisons are tobacco infusion, lime sulphur wash, and kerosene emulsion.

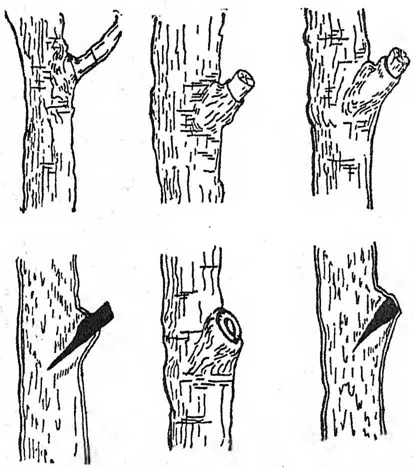

FIG. 222.—Improper removal of a limb may result in decay that is carried far into the tree. In the above, a stub was left, which does not heal over; the stub finally decays, and falls out. The dark-colored portion represents decayed tissue. (Redrawn from Solotaroff, in Shade Trees in Towns and Cities.)

Tree surgery. The work of various wood-destroying fungi, and mechanical injuries of different sorts, may necessitate special surgical methods to prevent the destruction of trees. The underlying principles in these methods are (1) the removal of all diseased or dead tissue, so as to secure a fresh surface, thus permitting the development of wound cork; (2) the sterilization of the exposed surface; (3) the covering of the surface with some material which will not allow the entrance of fungi.

If fungi invade the tissue and cause decay, it is necessary to

remove some live tissue beyond that which is clearly dead. Common materials used to sterilize and cover the exposed surface are commercial creosote, asphaltum, tar, and Bordeaux paste.

POISONOUS PLANTS

Many hundreds of plants are known to be poisonous to man and domestic animals, and many more hundreds are under suspicion. The annual toll of human lives in the United States due

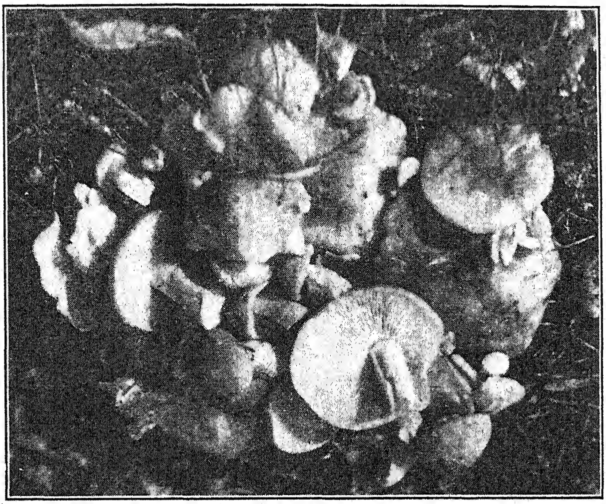

FIG. 223.—Edible mushrooms. It is often difficult to tell whether mushrooms are edible or poisonous.

to eating " toadstools " and the roots and berries of various seed plants is considerable; and the yearly losses of livestock, particularly on the western ranges, due to poisonous plants amounts to several millions of dollars.

From an early day the different Indian tribes have been skillful in preparing arrow poisons. A considerable number of different species of plants have furnished poison for arrow tips. The Egyptians were familiar with such poisonous plants as hyoscyamus, aconite, and conium. They also knew prussic acid, which they extracted from peach pits.

Forage poisoning in livestock is thought to be caused by various fungi. Ergotism is a disease of livestock caused from eating grasses which contain ergot, a fungus.

A number of the fleshy fungi are poisonous. Although there is no botanical difference between " mushrooms " and " toadstools,"

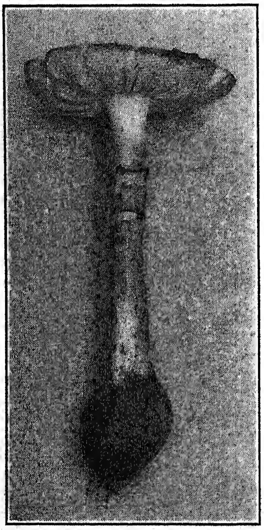

FIG. 224.—Deadly *Amanita*, a poisonous mushroom. Note the swollen base, and the ring on the stem. The gills bear white spores.

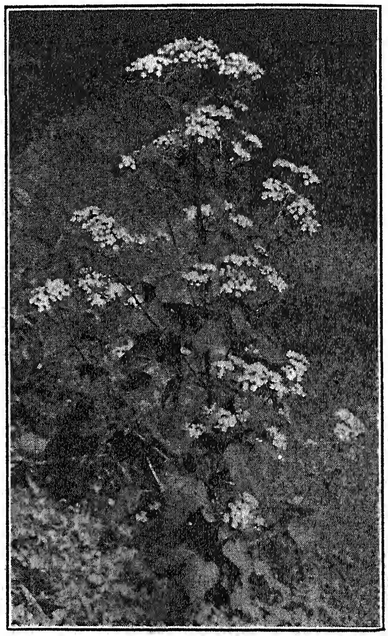

FIG. 225.—Among our poisonous plants is the white snakeroot of our pastures. It not only poisons domestic animals that eat it, but it has been found to cause milk sickness in man.

the former name is commonly applied to those believed to be edible, and the latter to those thought to be poisonous.

Nearly all the deadly poisonous fleshy fungi are species of the genus *Amanita*. This is a group of mushrooms with gills. Some of the species of *Amanita* have white caps, others have bright orange, red, or yellow caps; but in all the gills are white. This deadly

poisonous group is distinguished by the following combination of characters.

1. White gills.
2. A " ring " on the stem.
3. A cup at the base—the so-called " death cup."

When a mushroom shows these three features, it should be avoided. One should not depend upon the various rules-of-thumb for detecting poisonous mushrooms.

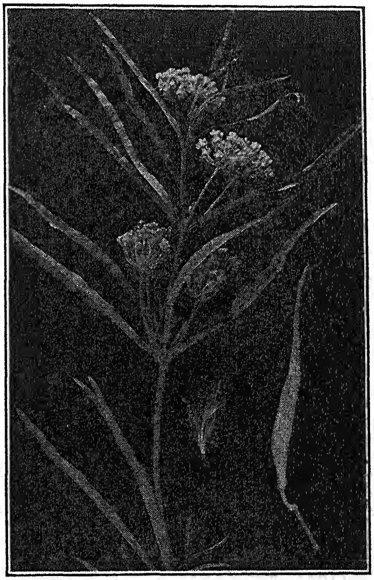

FIG. 226.—The whorled milkweed is an important stock poisoning plant.

A large number of plants are known to be poisonous from the presence of prussic or hydrocyanic acid. This acid is known to be one of the most deadly poisons, and it results from the presence in the plant of what is known as a glucoside, which must be acted upon by a ferment. A large number and a great variety of plants contain a hydrocyanic-acid-producing glucoside. Plants conspicuous in this class are cherry, peach, and other stone fruits, sorghum, kafir corn, and Johnson grass.

Plants chiefly responsible for injury and losses of livestock on the ranges of the western United States are as follows: larkspurs (*Delphinium*), aconite (*Aconitum*), death camas (*Zygadenus*), lupine (*Lupinus*), loco weed (*Aragallus* and *Astragalus*), water hemlock (*Cicuta*), milkweed (*Asclepias*), horsetail (*Equisetum*).

A number of plants are poisonous to the touch, causing skin diseases. Chief of these is the poison oak or poison ivy. No plant of the United States is more popularly recognized as harmful to man than this.

One of the most deadly poisonous plants is the water hemlock (*Cicuta*). Its poisonous principle is in an aromatic, oily fluid which is found chiefly in the roots; not infrequently children eat the roots, mistaking them for radish, parsnip, and other edible roots. The poison hemlock (*Conium maculatum*), closely related to water hemlock, is also a deadly poisonous plant, which has

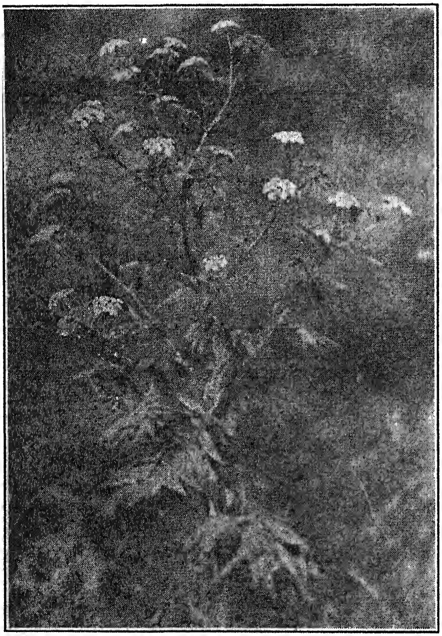

FIG. 227.—Water hemlock, an extremely poisonous plant.

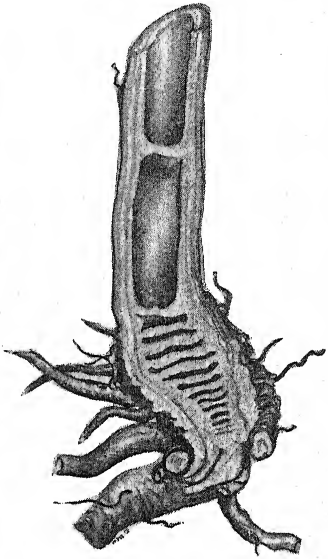

FIG. 228.—A portion of the rootstock and aerial stem of water hemlock, a very poisonous plant, cut in lengthwise section. Observe the narrow parallel compartments, a feature which enables one to identify this plant.

become naturalized in the United States. It is a native of Europe. It is the plant a decoction of which was administered to Socrates and caused his death.

HAY-FEVER PLANTS

It is now known that pollen is one of the chief causes of hay fever or bronchial asthma. The plants which give the most

trouble are principally weeds, and certain wind-pollinated trees which produce an abundance of pollen. Listed among the worst hay-fever plants are the following: ragweeds, wormwoods, pigweeds, Russian thistle, many grasses, including corn, oats, timothy, and wheat, and such trees as oak, black walnut, cedar, elms, and poplars.

The amount of pollen given off by certain plants is enormous. It has been computed that a single plant of ragweed (*Ambrosia trifida*) gave off between 8 A.M. and 1 P.M. in one day approximately 8,000,000,000 pollen grains. These are carried by the air currents, and reach the membranes of the respiratory tract. If the individual receiving them is "sensitive" to the particular pollen, he develops hay fever.

FIG. 229.—One of the ragweeds, a plant which produces an abundance of pollen. It is a well-known hay fever plant.

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The Tropical Crops, by O. W. BARRETT, published by the Macmillan Company, New York, 1928. 445 pages, 24 plates. Forty per cent of the earth's surface is in the tropics. The crops of the tropics now "supply a very prominent part of the international trade in foodstuffs, fibers, and industrial oil materials." This is a very readable account of such topics as tropical field practices and conditions, living conditions for the tropical planter, and the most important tropical crops.

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the Macmillan Company, New York, 1922. In six large volumes, a total of 3639 pages and 4056 illustrations. It is described as a "discussion, for the amateur, and the professional and commercial grower, of the kinds, characteristics, and methods of cultivation of the species of plants grown in the regions of the United States and Canada for food, for ornament, for fancy, for fruit, and for vegetables; with keys to the natural families and genera, descriptions of the horticultural capabilities of the states and provinces and dependent islands, and sketches of eminent horticulturists.

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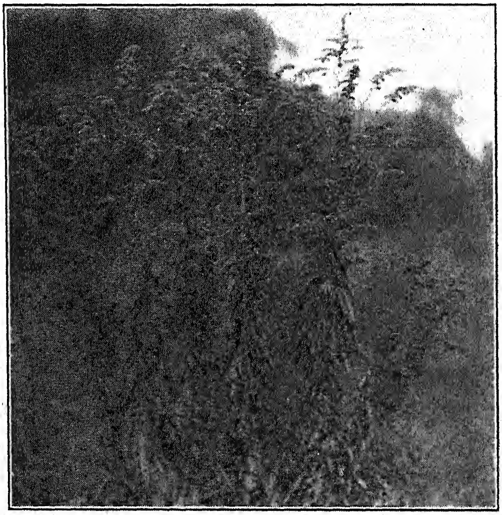

Fig. 230.—The golden rod is a hay fever plant. However, as its pollen is sticky, it is not a serious offender.

pages and 458 illustrations. It contains chapters on bacterial poisons, dermatitis, forage poisoning, poisoning from fungi, poisoning from various flowering plants, fish and arrow poisons, classification of poisons, symptoms and antidotes, the production of poisons in plants, chemistry of alkaloids, glucosides, etc., and a catalogue of the most important poisonous plants of the United States and Canada, and also a complete bibliography of poisonous plants.

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unfavorable water relations, diseases due to improper air relations, diseases due to high and to low temperatures, diseases due to unfavorable light relations, diseases due to manufacturing or industrial processes, diseases due to control practices, virus diseases, and the great number of diseases due to parasitic organisms such as bacteria, slime molds, rust fungi, smut fungi, etc.

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Numbers in bold-face indicate pages carrying illustrations.

P